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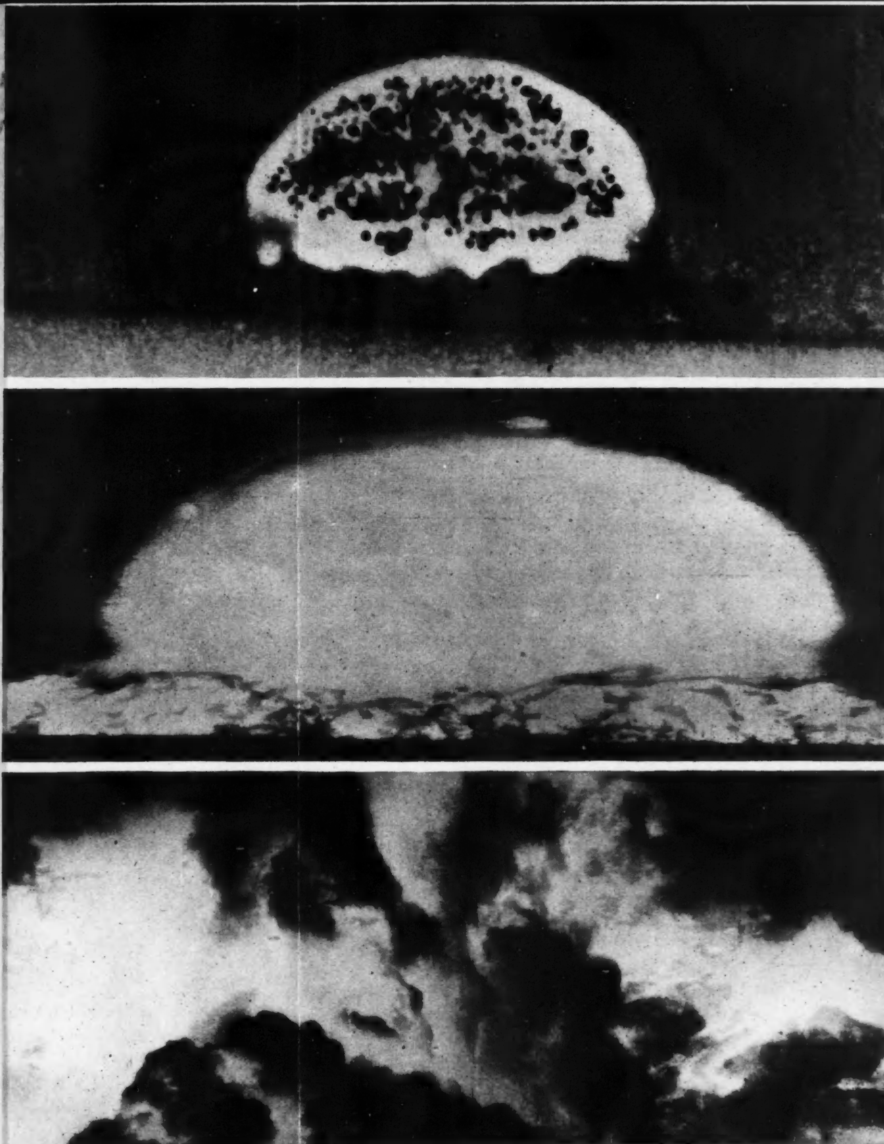

Monthly Notebook

Science behind the Atomic Bomb
DAVID S. EVANS M.A., Ph.D., F.Inst.P.

Greatest Scientific Gamble

Radar
Sir ROBERT WATSON-WATT, C.B., F.R.S.

The British Bats
BRIAN VESEY-FITZGERALD, F.L.S.

Night Sky in October
M. DAVIDSON, D.Sc.

Junior Science

Far and Near

PAPER ECONOMY
Reduced in thickness, but not in contents. Approximately 30,000 words in each issue.

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THE MAGAZINE OF SCIENTIFIC PROGRESS

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The Progress of Science

WE ENTER THE NEW AGE

IT is now nearly two months since the news flashed across the world that the first atomic bomb had been dropped on Hiroshima. The public recognised instinctively that this was news much bigger than any war which has ever been fought and that it portended far-reaching changes in the whole life of man. Now we must get used to living in a new world, and we must attempt to assess what kind of world it is likely to be and how it will affect our ordinary lives.

The simple facts are that a mass of uranium 235, probably no larger than a cricket ball, was dropped on a Japanese city. It destroyed that city and killed possibly a hundred thousand people. The immediate effect was to convince even the Japanese, perhaps only temporarily, that war is a fool's game. Even so, a large number of ministers of religion and private persons of distinction protested against the use of the bomb as an inhuman invention. It is, however, very noteworthy that several of the protests recognised the distinction between the dominating political and military needs and the personal inclinations of the scientists; few accused the scientists of "wickedness".

The wider implications are, first, that science is now palpably a department of human activity which no one can ignore. Secondly, that this last piece of secret research is not an isolated discovery, but only the latest step, and a logical one, given the condition of the world, in a chain of investigation beginning at least 50 years ago. The earlier links were forged in public for all the world to see, and the last, secret step, its practicability demonstrated with such terrific and terrifying effect, could be taken by any nation possessing the necessary technical manpower and the industrial resources. Thirdly, one of the incidental bits of nonsense which disappeared with Hiroshima was that fundamental research cannot be carried on in an organised way, for although the question as to how far the applied research involved fundamental advances is a debatable one it cannot be denied that in the course of the work pure physics has been advanced a couple of decades in five years.

This last point is a scientist's point. What the public is most interested in are the possibilities for the future. There can be no doubt that the existing economic and political organisation of the world is in for a severe shaking. The pattern of world security is drastically altered. The world resources of power have not yet been changed, but it is possible that, within our own lifetimes, they will be altered almost out of recognition. This will, doubtless, need new programmes of research, but that research will be carried out inevitably. Let us make no mistake. The result we have seen has come out of work which has done no more than cast a single ray of light into our black ignorance of the properties of the atomic nucleus. There will be bigger and more worth-while discoveries yet to come, and to be digested by our world order. This is only a sample of the kind of control which man can acquire over his environment. The most crucial question of all is whether mankind is going to shrink from the task of running the world, or whether he will take the power and the glory and come into his own kingdom at last. If man does not now justify his own claim to rationality and intelligence then he is finished. This has always been so in this scientific age; the atomic bomb has merely driven home the point.

The Atomic Bomb and World Security

WHEN the radio announcement of the dropping of the first atomic bomb was made one of the audience remarked with the deepest gloom, "They will be dropping them on us in ten years from now." On the whole, the public reaction seems to have been one of conviction that it would be impossible to control the invention coupled with regret that it had been used at all. But, as one of the leading workers in the field has pointed out, the discovery of the atomic bomb at this particular moment, and even—though this startling statement must be made with caution—the coming of the war when it did, are likely to prove most fortunate factors. It has already been remarked that any nation possessed of the necessary industrial and scientific resources could produce these bombs and, in fact, the Germans were working on the problem and might have succeeded in solving it within a matter of months. Now the world is sharply split into the United Nations and the rest. The control of the atomic bomb is not in the hands of the rest, but if we are so foolish as to quarrel among ourselves, then we may indeed have atomic bombs descending on our cities within ten years.

The striking characteristics which differentiate the atomic bomb from all other weapons are: the complete and widespread devastation which can be caused by single bombs; the smallness and portability of the missile; and the absence of any but the smallest chance of protection from its effects, or of counter-measures to it. The implications are obvious. The only effective protection would be a means of ensuring the destruction of every single aircraft of an attacking force. It may be that a vastly improved radio-location system and entirely new methods for the destruction of aircraft would be the answer, though whether this would be practicable is open to doubt. If any future war were to start it would be a case of all or nothing: either the defenders could eliminate all the attackers, or they themselves would be likely to be exterminated in a very short time. But the increasing heights at which jet-propelled aircraft will be able to fly, and the apparent lack of necessity for aiming atomic bombs with the accuracy necessary with all other bombs, seem, as far as can now be judged, to weigh heavily in favour of the attacker. It seems as if the atomic bomb is the weapon to which there is no effective answer.

To conduct war on these terms would place a premium on rapidity of attack and on secrecy of preparation. Once a war had started the initial aggressor would have an advantage, but it would not necessarily be an overwhelming one. With long range radio-location systems constantly in operation the defenders would, in all probability, have sufficient warning to enable them to get their own bombers over the enemy cities within a very few minutes of the delivery of the aggressors' attack. Both air fleets would then return to devastated homelands. In a war with such weapons victory would go to the combatant who could devastate most of his enemy's territory first—but it would be a victory won only at the price of wholesale destruction on both sides.

There will undoubtedly be people, for example some who have a considerable stake in the existing military set-up, who will try to pooh-pooh the effects of the atomic bomb. Wider dispersal of industries would reduce its effectiveness and the placing of factories underground is a practicable defence measure, they may argue. But it will be impossible to put all the workers' houses underground so that protection for them is quite out of the question. The atomic bomb is a weapon for the destruction of civilian morale, outstripping to an unprecedented degree all counter-measures now conceivable. The atomic bomb has made war ridiculous. The writer is well aware that arguments similar to those advanced above were heard after World War I. The horrors of being bombed with 100-pound bombs then seemed so great that it was held that the prospect of mutual destruction would be a strong deterrent to future wars. It did not prove so: modern man, if he has not become blasé about being bombed with ordinary sized missiles, at least developed a sort of resignation, based mainly on the idea that, after all, one had a chance. This time we haven't. If once we let things deteriorate so far that there is even an outside chance that atomic bombs will be exchanged, then it is too late. Our business now must be to learn politics; to understand foreign policy; and to make quite sure that there will be no mistakes in foreign policy.

However, this is the gloomy side of the picture. The divines warn us that man's spiritual stature is yet too puny to enable him to control these dangerous toys which have been put into his hands. Frankly, we find these arguments out of date. It is not true that we have learned nothing: it is not true that man cannot control his own destiny. Look around and, on all sides, there is the evidence that a new spirit is abroad in the world. The century of the Common Man is starting, and it is beginning with the public manifestation of the common sense, decency and intelligence of the ordinary man. If the doctrines of our own unworthiness and of original sin are to diminish our faith in ourselves, and to hinder the taking of the reins by the Common Man, then they do us a disservice and endanger our future. Herein lies the source of the one danger which faces us: that we shall not realise quickly enough that we are living in a new world, and that we shall have to think and act differently in consequence.

The first big consequence of the atomic bomb is that it has ended war if only we have the faith to see that it is so. The second is that it creates at once an overwhelming necessity for a world community. Not only are battleships and tanks virtually obsolescent, but so are our political institutions. The world must unite or perish and the new institutions—the World Security Council and the like—portend a world government which will come into being and which will replace even the apparently revolutionary international organisations which have been born out of the second world war.

However, many different sorts of world community are possible. What sort of world organisation is needed for a world possessed of the powers of the magician and the alchemist, and with the prospect of these powers being added to? The first necessity is to prevent war, and that now means the control of existing forms of atomic weapons. As things stand at the moment, the production of atomic weapons is a tremendous industrial undertaking requiring not only access to sources of uranium, but the specialised productive capacity. This means that the great powers, as at present constituted, are the logical controllers of the world. In international federative action the paramount factor has become, not the ethnographic self-determination or pseudo-democratic system of voting by which so much store was set in the framing of the Versailles Treaty and the League of Nations, but the concentration in responsible hands of world supplies of uranium and of the means of its utilisation. If this is omitted, all other provisions would fail. Only the great powers have the necessary industrial capacity to produce atomic weapons. Their first task will be the control of the technical knowledge, the control of uranium sources, and the supervision of industrial effort in enemy countries at such a level that clandestine production is made impossible.

At first these requirements should be easy enough to satisfy, but the system of control sketched out cannot have this form permanently. In the first place, any attempt to maintain, as a permanent feature, secrecy in an important department of modern physics would be strongly resisted by the scientists of the world. For the existence of a permanent blanket of secrecy over any department of scientific work is a negation of the whole spirit of service and unfettered inquiry which is an essential part of science. We may be sure, however, that even if this were tried it would fail. There is, in the long run, no such thing

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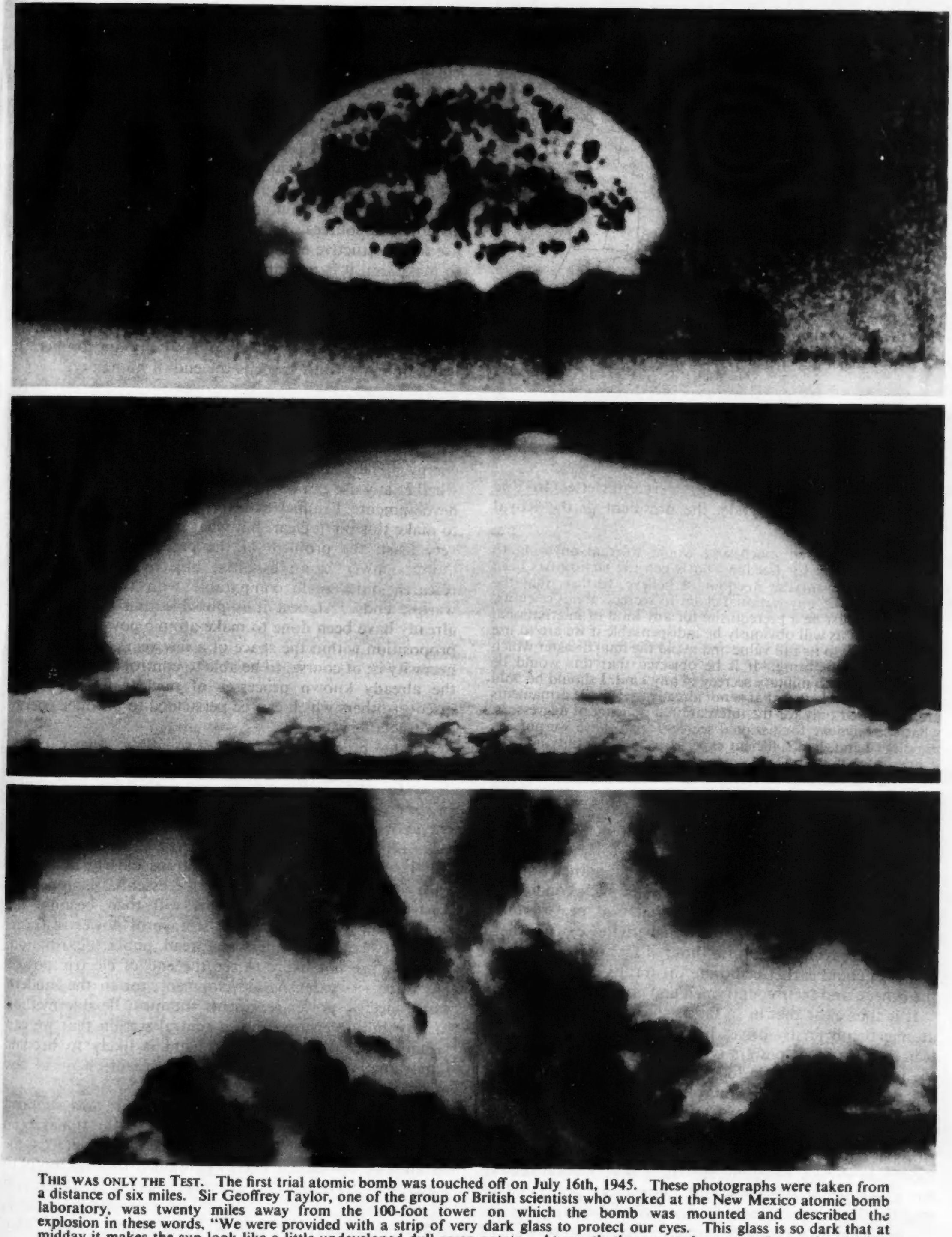

This was only the Test. The first trial atomic bomb was touched off on July 16th, 1945. These photographs were taken from a distance of six miles. Sir Geoffrey Taylor, one of the group of British scientists who worked at the New Mexico atomic bomb laboratory, was twenty miles away from the 100-foot tower on which the bomb was mounted and described the explosion in these words. "We were provided with a strip of very dark glass to protect our eyes. This glass is so dark that at midday it makes the sun look like a little undeveloped dull green potato. At exactly the expected moment, I saw, through the dark glass, a brilliant ball of fire which was far brighter than the sun. In a second or two it died down to a brightness which seemed to be about that of the sun, so realising that it must be lighting up the countryside I looked behind me and saw the scrub-covered hills 22 miles away from the bomb lighted up as though by a midday sun. Then I turned round and looked directly at the ball of fire. I saw it expand slowly, and begin to rise, growing fainter as it rose. Later it developed into a huge mushroom-shaped cloud and soon reached a height of 40,000 feet."

This map shows the location of the atomic bomb laboratory near Los Alamos, New Mexico. The two major production plants are at Richland and Oak Ridge.

as secret research. What one man has done, another can do. The idea that suppression of developments can be substituted for an honest and open attempt to use them constructively is a centuries-old fallacy.

This point was discussed in a recent letter to *The Times* from Sir Henry Dale, the president of the Royal Society. He wrote:

> We have tolerated much and would tolerate anything to ensure the victory for freedom; but when the victory has been won we shall want the freedom. I believe, further, that the abandonment of any national claim to secrecy about scientific discoveries must be a prerequisite for any kind of international control, such as will obviously be indispensable if we are to use atomic energy to its full value and avoid the final disaster which its misuse might bring. If it be objected that this would be incompatible with military secrecy of any kind, I should be bold enough to ask whether that is not already useless. If armaments are to be used only for the international policing of aggressors, what use have we for national secrecy? And have we not, on the other hand, had sufficient experience of the futility and the danger of pacts and agreements which impose quantitative limits on known and obsolescent types of armament, and leave the right to qualitative improvements and new developments in secret?

Sir Henry Dale made a further point in these words: "It (military secrecy) is bound, if we tolerate it, thus steadily to widen its encroachment and strengthen its hold on the freedom of science. Soon, under such conditions, many of the scientists of some country at peace would find themselves in secret competition with those of another, as ours were ready to be with those of Germany in war, as to which could earlier elaborate the means of annihilating the others, and their countrymen and country with them."

It is thus clear that in so far as the development of the atomic bomb finally drives home the point that modern war between great powers is war between scientists, then the future pattern of world security is also going to be the determining factor in the future of scientific inquiry.

The necessity for secrecy until the pattern of security is sketched out will be admitted, but this means of control can be only temporary. (On one detail of the bomb secrecy is already questionable: there is very good reason for revealing at once its real destructive power. The backing for a world security system is ultimately public opinion which will, unless supported by facts, be vulnerable to the insinuations of propaganda designed to minimise the importance of atomic bombing. If the public's sense of responsibility were to be undermined by such propaganda the effects would very likely be disastrous.) Further nuclear research may well reveal entirely new possibilities for which the essential material may not be uranium but some other substance, perhaps with a markedly different geographical distribution. It follows that the only hope of securing permanent control lies, not in the attempt to maintain secrecy, but in the establishment of some kind of world government which can maintain a close economic and political control over all potential sources of nuclear power and can direct their use to constructive ends. This may seem a large assertion to make, but it is probably the case that the revelation of atomic power as a practical proposition spells the end, not only of the private control of the means of production, but even the end of the separate divisions of humanity into distinct nations with their potentiality for conflict. If it does not spell this it spells the end of humanity.

Atomic Power and World Economics

The atomic bomb represents the destructive use of atomic energy. The immediate and obvious question to ask is whether any use can be made of this invention for peaceful development. Insufficient information has been revealed to make this point clear, but what is certain is that, at the very least, the problem of the peaceful exploitation of atomic power is an essential objective for immediate research on a scale comparable with that devoted to warlike ends. At best it is possible that sufficient may already have been done to make atomic power a practical proposition within the space of a few years. The primary necessity is, of course, to be able to control and slow down the already known processes of nuclear fission, or to discover others which can be persuaded to produce energy at a tractable rate.

At the present stage it is probably somewhat idle to speculate on the exact forms which atomic energy generators may take, but we can with some probability of being correct guess at the kind of changes which atomic energy will bring about in our present economic structure.

It seems likely that atomic energy generating stations will be fairly large fixed installations closely associated with the chemical works where the essential isotopes are separated. The chief problems will then become the distribution of power and the storage of power in forms sufficiently tractable for widespread public distribution. Thus we are not likely to see the end of electric power, but rather its extensive development, for in the modern world electric power represents the most flexible method of distributing energy from a central station that we can visualise. Coal, on the other hand is likely to become important not as a fuel but as a source of chemical raw materials.

The world also needs locomotive power, now supplied by more or less readily transportable fuels. It has been said that the Queen Mary could be driven across the Atlantic on the atomic energy contained in a teacupful of water, but it is hard to envisage this vivid illustration of the energy locked up in the atom becoming practicable. If the energy is really to be as concentrated as that, then there would seem to be almost an *a priori* difficulty about releasing it with sufficient gradualness. It may well be that an essential concomitant of peace-time research into

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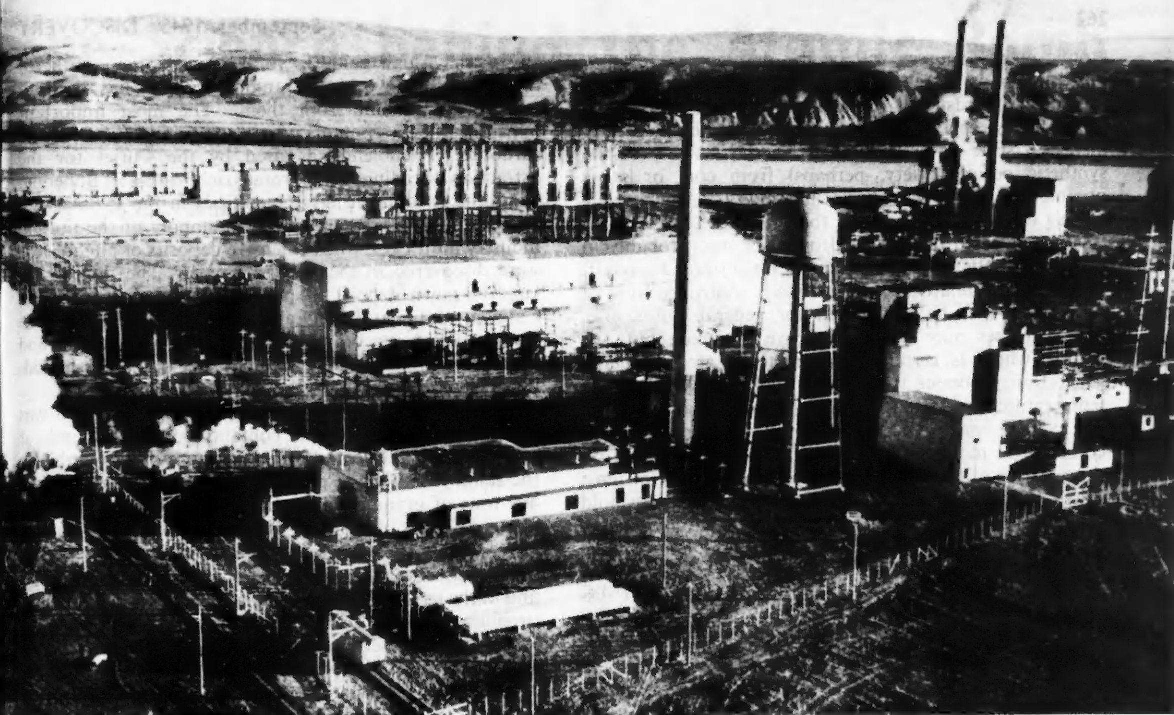


(*Above*) A view of the atomic bomb plant at Richland near Pasco, Washington, known as the Hanford Engineer Works. (*Below*) The other vast American plant, the Clinton Engineer Works, was built on a reservation covering 59,000 acres at Oak Ridge, Tennessee.

atomic energy sources will be the development of new kinds of fuels which, though highly concentrated by present standards, will represent a tractable dilution of the primary energy sources. For example, a greatly increased scale of production of synthetic fuels (of the synthetic petrol variety, perhaps) from coal or other organic sources might be a possibility. Alternatively atomic energy might be used for the large scale electrolysis of water to produce hydrogen for use, probably in liquid form, for jet-propelled or rocket-propelled aircraft. Clearly only a relatively safe and easily controlled form of fuel could ever be distributed for general public use. These guesses may very well prove incorrect, but one feature which is certain to characterise atomic energy generation processes is that they will involve very high temperature generation of energy. In nuclear processes the average energy of ejected particles is very high and corresponds more to the sort of temperatures found on the surfaces of the hotter stars or in the interior of most stars. This would mean that any ordinary container would be vaporised if inside it were carried on atomic energy generation processes proceeding at anything approaching their normal energy density. What seems essential is that the high speed products of some process of nuclear disruption should be absorbed by some working substance at a temperature of not more than a few thousand degrees. To put it in technical language, the particle energies and the quanta associated with the nuclear disintegration are probably too high for direct use, and must be converted to lower temperatures.

Even so, the prospect is that temperatures far higher than those in general industrial use will eventually become common. A most important result would then be a marked gain in the efficiency of use of this energy. The higher the initial temperature of a working medium which is eventually to be condensed to normal temperatures, the higher is the efficiency of conversion of this energy into mechanical work. With the very high temperatures of working which may be introduced this conversion will approach 100 per cent, probably more than twice the efficiency which is now obtainable under the best conditions. There might be a quite considerable loss of energy in the conversion process from primary atomic energy, but even here the temperatures concerned would probably be so high that most of the energy would be usable.

There remain two other questions. First as to whether it will ever be economic to produce atomic energy as judged by the number of man-hours spent in its production. This is a question where there is no real information to serve as a guide and where much depends on research on methods of isotope separation perhaps yet to be undertaken.

Uranium's Distribution

The other question concerns the essential raw materials. For the destructive purposes of the atomic bomb the key element is uranium: whether this will remain so is not at all certain, but the impression given is that there is a considerable probability that the nuclei in which fission can take place will all be heavy nuclei and rather near to uranium in the atomic weight table. If this is correct, then the known distribution of uranium ores will provide at any rate a rough guide to future possibilities. Hitherto the reason for working uranium deposits has been to extract the radium from them. The most important minerals which contain uranium are pitchblende and carnotite. Pitchblende as used by the Curies for the extraction of radium came from Joachimsthal in Bohemia. Carnotite is found in large quantities in the U.S.A., and the United States had a virtual monopoly of the radium industry until 1923, when extensive deposits of pitchblende were discovered in the Belgian Congo. The richest and largest known deposit of pitchblende was discovered in Canada, at Great Bear Lake. This makes Canada the leading country in uranium production, but radium- and uranium-bearing minerals occur all over the world, including several other parts of the British Commonwealth.

The United States production of uranium in 1938 was about 25 tons which would contain about 300 pounds of uranium 235, the isotope used in the atomic bomb. In the same year Canada produced 75 grams of radium and 400 tons of uranium salts. In 1938 the U.S.A. imported about 180 tons of uranium salts, probably mainly for use in connection with steel production. In 1939 U.S.A. imports of uranium oxide and salts had risen to 900 tons, and in the next year, imports of salts were 120 tons, and of uranium ores were 1,250 tons.

How far these increases were connected with the increased production of heavy industry, and how far with atomic bomb research is not clear, except that at this time, even in Britain, atomic bomb research was only just starting and American collaboration had not gone very far.

If uranium remains the source of nuclear energy it is likely that these extensive deposits will become the scene of new developments of industry. Had political circumstances been different the discovery of the atomic bomb might well have transformed Canada into an independent great power. As it is, there may well be a shift in the existing location of industry on the north American continent and a new tide of development in some of the British dominions which possess uranium ores. However, many prerequisites will need to be satisfied before this comes about. The capital needed for development, both monetary and in technical manpower, is very great, and what one can expect is a slow shifting of the centre of gravity of world power production, whose course may be changed by new technical discoveries.

Atomic Weapons and the Progress of Science

Scientific knowledge has been used to produce many weapons of war, but there can have been few cases in which the science was so "pure" or so fundamental as in the case of the atomic bomb. The work derives with simple directness straight from a long continued programme of pure research. The actual applied research carried out with the recognised aim of producing the bomb was of a kind which in other circumstances would have been almost universally called pure. Rarely has there been so forceful an example of the lack of any true division between pure and applied science, or a more direct demonstration of the way in which the posing of a large enough practical problem almost invariably brings in its train advances in pure science. In this case we have seen

[*concluded on p.* 274

The Science behind the Atomic Bomb

DAVID S. EVANS, M.A., Ph.D., F.Inst.P.

THE atomic bomb represents the first utilisation on any considerable scale of energy released from atomic nuclei. The study of the nature and structure of atomic nuclei has occupied a large part of the experimental resources of fundamental physics during the last quarter of a century, and an even greater proportion of the energies of theoretical physicists. It thus becomes necessary first to describe in outline some of the most important advances in physics which have been made during that time. It must be emphasised that the outline is necessarily rather sketchy and that anything like a comprehensive account of atomic research would have to be very many times the length of this article.

The Bohr-Rutherford Atomic Model

The modern picture of the atom represents it as similar in some ways to the solar system. At its centre, corresponding to the sun, is a heavy nucleus with a positive electric charge. Round it circle a number of negatively charged electrons, which correspond in this picture to the planets. The analogy is, however, rather superficial. The forces which hold the planets in their tracks are gravitational: the forces holding the electrons are those of electrostatic attraction between opposite charges. There is no reason, apart from the accidents of cosmological history, why the solar system should not have as many or as few planets as one pleases. The number of electrons normally held by an atom is determined by the fact that the total negative electric charge of the electrons just balances the positive electric charge on the atomic nuclei. Again, the planets are all of different masses and there is no reason why they should not move in any orbit consistent with the laws of gravitation. The electrons, on the other hand, are all precisely similar and can only move in certain definite orbits around the central nucleus.

In describing a system of this sort it is necessary to use suitable descriptive units. The unit of mass used is that of the nucleus of the lightest known atom, hydrogen, which weighs only $1{\cdot}6 \times 10^{-24}$ grams, i.e. a million million million million of them would weigh 1·6 grams. The mass of the electron is $\frac{1}{1850}$ of this and the electric charge on the hydrogen nucleus is $4{\cdot}77 \times 10^{-10}$* electrostatic units. The charge on the electron also has this value but is negative.

It follows, then, that a hydrogen atom has one electron circulating round it, the positive charge of the hydrogen nucleus (often called a *proton*) just balancing the negative charge on the electron. The number of electrons which are held by any atomic nucleus is called the *atomic number* of that atom, and it is this atomic number which distinguishes the chemical nature of the atom. For example, hydrogen, already cited has an atomic number of 1; oxygen has eight electrons, and hence atomic number of 8. Uranium, the element which had the highest atomic number known in 1939, has 92 electrons. The series of atomic numbers is continuous from 1 to 92, so that there were 92 different chemical elements then known.

The reason why the atomic number is the determining factor in chemical behaviour is that chemical linking of atoms in groups, to form molecules, takes place because of the interaction of the groups of electrons possessed by the constituent atoms. To put the matter crudely, the electrons are the jam which sticks atoms together in chemical combinations, and it therefore follows that the number of electrons possessed by any atom, and the configurations of the orbits of these electrons, are the determining factors in chemical combination.

This picture was painted not by one, or even by a few scientists. It was Rutherford who in 1911 realised the nuclear nature of atoms, and Bohr who in 1913 proposed this model. One of its chief merits at that time was that it explained, in terms of the quantum hypothesis of Planck, the observed capacities of atoms for emitting and absorbing light of certain definite wavelengths characteristic of each chemical species (Figs. 2 and 3). The model was successful in accounting also for many other physical and chemical properties of atoms; in particular it explained both the regularities of chemical properties exhibited by certain groups of chemical elements and the property possessed by certain substances of emitting electrons when light of less than a certain wavelength was absorbed by them.

All the chemical processes we know—combination, oxidation, and so on—are explicable in terms of rearrangements among the various chemical species of atoms or of changes in the orbital configurations of the electrons in atoms. In many such processes energy is emitted. The burning of coal is a regrouping of atoms and molecules and their combination with atmospheric oxygen, and results in the liberation of energy, and the rate at which these processes go on is determined by the temperature of the surroundings. All chemical processes affect only the outer screen of electrons round each atomic nucleus, and have no effect on the nuclei themselves.

Natural Radioactivity

The first occasion on which a scientist noticed any process involving changes in an atomic nucleus was the observation by Henri Becquerel in 1896 that photographic plates wrapped in paper impenetrable to light rays were blackened when placed near certain mineral specimens. The effect was called *radioactivity* and was found to be due to the element uranium which was contained in the specimens. Later work led, in 1898, to the isolation by Pierre and Marie Curie of another metal, radium, contained in uranium ore in minute quantity and which exhibited the phenomena of radioactivity to a very much greater degree. Until recently the medical importance of radium led to a far greater concentration on this substance than on uranium.

At first the nature of radioactivity remained mysterious. It was a process proceeding at a quite definite rate that

* $10^{-10} = \frac{1}{10000000000}$

FIG. 1—Fast-moving α-particles derived from the disintegration of radioactive elements were the first projectiles used by scientists in their attempts to "split the atom" artificially. The first success with the method was achieved in 1919 when Rutherford demonstrated the transformation of nitrogen. The splitting of the nucleus of a single atom was first made visible six years later by Blackett. In this cloud chamber photograph an α-particle has effected the transmutation of a nitrogen nucleus into a nucleus of mass 17 and charge 8—the nucleus of an oxygen isotope—with the emission of a proton of high energy; the diagram gives the key to the paths of the different particles.

(Photograph by Professor P. M. S. Blackett)

was uninfluenced by changes of temperature which would have affected ordinary chemical processes. Under all conditions the rate of energy production remained constant, and in 1902 Rutherford and Soddy suggested that the only possible explanation was that the nuclei of radioactive atoms were breaking down and changing into some other atomic species. In any mass of uranium half the atoms undergo radioactive decay in 4500 million years and in any mass of radium half the atoms decay in 1·59 years.

The "radiation" from radioactive bodies was found to be of three kinds, called respectively alpha, beta and gamma rays. Alpha radiation was found to be the emission from the nucleus of a particle, called an alpha particle, subsequently identified with the nucleus of a helium atom. This has a mass four times that of the proton (hydrogen nucleus) and carries two positive electric charges. The consequence of alpha decay is therefore that the radioactive nucleus loses four units of mass and two units of charge; its atomic weight is reduced by four, and its atomic number by two, so that the final product is an atom of a different chemical species.

Beta decay was found to be the emission of an electron from an atomic nucleus, a process which did not change the mass appreciably, but by the removal of one negative charge left the nucleus with an increased positive charge and therefore capable of holding one more electron in its outer screen. Beta decay therefore increases the atomic number by one.

Gamma radiation is an electro-magnetic radiation of the same kind as X-rays, visible light, and radio waves, the distinguishing feature being that gamma radiation affects neither the mass nor the atomic number of a nucleus, but it is associated with changes in these numbers, for gamma radiation is often emitted in association with radioactive changes of the other two types and represents the removal of energy from the nucleus surplus to what is needed for settling down into a new atomic state after a radioactive change has taken place.

As an example of these changes we may quote the case of uranium which decays in several stages—one stage of alpha decay, two of beta decay, and two of alpha decay. The uranium atom has now changed into radium, passing through four intermediate substances in the process. The total of three stages of alpha decay reduced the mass of the nucleus by 12 units, and would reduce the atomic number by 6 units were it not for the fact that two of these are offset by the two stages of beta decay. The uranium (mass 238, atomic number 92) thus changes to radium (mass 226, atomic number 88) and this slow continuous transmutation accounts for the presence of radium as an admixture with uranium in its ores.

Isotopes and the Neutron

We have so far spoken of two types of particle—negative electrons and positive atomic nuclei. In 1932 Chadwick discovered a new type of particle of mass almost exactly the same as that of the proton but having no charge. This particle he called the *neutron*. It provided a general explanation of a phenomenon suggested by Soddy in 1910 and investigated extensively by Aston in the years after World War I. This was the existence of *isotopes* or elements which are chemically identical but of different atomic masses. As we have seen, the chemical properties

TABLE I.

Name	*Mass in proton units*	*Electric Charge in proton units*
Proton	1	1
Electron or β particle	$\frac{1}{1850}$	-1
Positron	$\frac{1}{1850}$	1
Meson	about $\frac{1}{10}$	± 1
Neutron	1	0
Deuteron	2	$+1$
α particle	4	$+2$
Neutrino	$\frac{1}{1850}$	0

THE SEQUENCE OF MODERN ATOMIC DISCOVERY

1896 Becquerel discovered radioactivity of uranium
1897 J. J. Thomson discovered electron
1898 Pierre and Marie Curie isolated radium
1901 Planck's quantum theory
1905 Einstein's special theory of relativity; showed equivalence of mass and energy
1910 Soddy suggested existence of isotopes
1911 J. J. Thomson: experimental demonstration of the existence of isotopes of neon
1911 Rutherford's hypothesis of the nuclear atom
1912 C. T. R. Wilson's cloud chamber
1913 Bohr's theoretical development of Rutherford's atomic hypothesis
1919 Rutherford obtained first clear proof of artificial transmutation of an element when nitrogen was bombarded with alpha particles
1925 Blackett: first photographs obtained, using Wilson cloud chamber, of nuclear collisions involving transmutation
1930 Dirac's theoretical prediction of positron
1932 Cockroft and Walton: artificial disintegration of lithium by proton bombardment
1932 Chadwick discovered the neutron, emitted when beryllium was bombarded with alpha particles
1932 Urey and Brickwedde discovered heavy hydrogen
1932 Anderson and Blackett discovered positron (positive electron) independently
1930 E. O. Lawrence built first cyclotron
1933 Frederic Joliot and Irene Curie-Joliot: production of artificial radioactive elements
1934 Fermi: bombardment of nuclei of heavy elements with neutrons; Pauli's hypothesis of the neutrino
1935 Yukawa postulated existence of meson (mesotron)
1938 Anderson and Neddermeyer: experimental evidence for existence of meson
1938 Hahn and Strassmann: experimental evidence of nuclear fission in uranium
1939 Frisch and Meitner: hypothesis of nuclear fission
1939 Joliot, Halban and Kowarski: experimental proof of neutron emission in nuclear fission
1939 Bohr-Wheeler theory of nuclear fission
1940 Nier, and Booth, Dunning and Grosse, independently obtained experimental verification of fission of U 235 by slow neutrons

of an atom depend only on the charge on the nucleus; they are not affected at all by the mass of the nucleus. Aston had, in fact, found that many species of chemical elements could exist in several forms of different masses, and he succeeded in separating these in the minute quantities needed for identification by means of the mass spectograph, an instrument depending for its action on the slight differences in behaviour of isotopes of different mass moving in magnetic and electric fields. (An item about the mass spectograph appeared in *Discovery* in May, 1944.)

If the atomic nuclei are regarded as composite themselves and consisting of protons and neutrons, this discovery would provide an explanation for the existence of isotopes. For example, in the case of chlorine with atomic number 17, the necessary 17 positive charges on the nucleus would be provided by 17 protons. But chlorine has two main isotopes of masses 35 and 37 so that the residual mass in these two cases could be provided by the inclusion of 18 and 20 neutrons respectively.

It is probably true that atomic nuclei do consist of protons and neutrons though it must not be assumed that these particles in any sense retain their identity when incorporated into the nuclear structure. Since neutrons have no charge there is no electrostatic force between neutrons, or between a neutron and a proton, and it is assumed that there are other forces, of an extremely short range, whose action is essential for the existence of atomic nuclei.

Reference should also be made here to the existence of other types of elementary particle which play a role in nuclear structure. These include the positive electron, or positron, which exists as a free particle only until it meets an ordinary negative electron. Positrons are emitted from the nuclei of certain species of atoms during radioactive decay. Another type of particle is the meson,* predicted by Yukawa in 1935. Mesons have the same charge as an electron or proton, and may be of either polarity. They have a mass of the order of 200 times that of the electron and have, as free particles, only a temporary existence, decaying in a time of a few millionths of a second. They have been observed only in connection with cosmic ray showers, but on theoretical grounds they are believed to play an important role in connection with the neutron-proton interactions in nuclei, and it was from considerations such as these that Yukawa made his prediction in advance of the observation of mesons by Anderson and Neddermeyer. Lastly there is the neutrino, which it is believed must appear in beta decay. This has no charge and its mass is small compared with that of the proton.

The importance of these particles for the theory of nuclear structure is that, although from some points of view it is sufficient to regard nuclei as aggregations of neutrons and protons, the separate identity of these particles is lost and a nucleus undergoing radioactive decay may emit either positive or negative electrons or neutrinos which at first sight would not seem to be available.

However, to examine this question more closely would involve us in too severe complications while the neutron-proton nuclei do provide a sufficiently adequate basis for a general discussion (*see* Table I).

Investigations of Atomic Structure

This general picture of atomic structure was built up by very many experimental and theoretical investigators over

* For a discussion of positrons and mesons see the article on Cosmic Rays by Dr. M. McCaig, *Discovery*, May 1944, pp. 136–140.

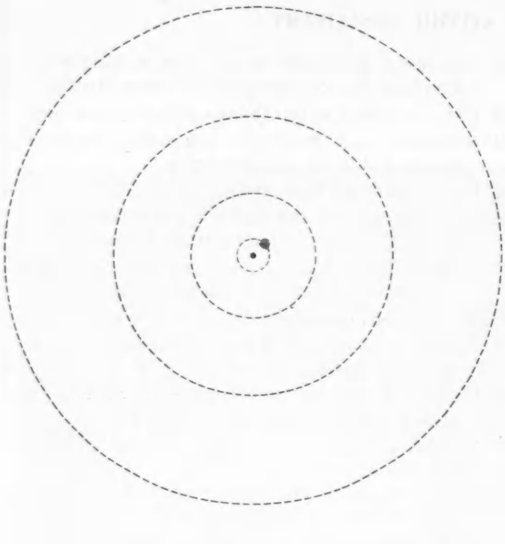


FIG. 2.—One series of possible orbits for the single electron in the hydrogen atom. Small amounts of energy are emitted or absorbed by the atom, e.g. in chemical changes, when the electron jumps from one orbit to another.

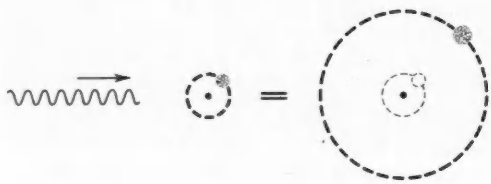


FIG. 3.—When radiation of the correct wavelength is absorbed by a hydrogen atom the electron jumps from an inner orbit to an outer. Later on the electron will spontaneously jump back and the radiation will be re-emitted.

the course of more than a quarter of a century, and in a chronological order different from that given here.

Some reference to experimental methods used is essential if a correct picture is to be sketched. Generally speaking the methods for the investigation of nuclear structure have all depended on the projection with high velocities of various types of atomic particle at targets formed of thin films of the substances under investigation. The object has been to cause the bombarding particles to collide with the atomic nuclei under observation and to produce disruption of them. The nature of the processes occurring can then be inferred from a study of the tracks followed by the fragments of the disrupted nuclei (Fig. 7). The actual bombarding atoms and the resulting fragments are all invisible, but their tracks can be rendered visible by means of a device known as a "cloud chamber" developed by C. T. R. Wilson. This device causes the deposition of a line of minute water drops along the tracks followed by the atomic particles.

The methods of producing fast particles suitable for atomic bombardment have varied in detail but in general they all depend on the fact that a charged particle will experience a force when placed in an electric field (Figs. 5 and 6). Thus, for example, protons between two metal plates which are at a potential difference of one million volts will move rapidly away from the positive pla. and towards the negative one. The velocity which the) acquire depends on the potential difference used, and it is customary to express the energies of atomic particles, not in terms of their speed or kinetic energy, but in terms of electron-volts—the energy that is acquired by a particle with a single electronic charge as it passes between two plates whose potential difference is one volt.

As faster and faster particles were required the potential differences used became higher. An important device which did not entail the use of exceptionally high voltages, but which could produce particles of high energy, was the cyclotron (Fig. 6), invented by Dr. E. O. Lawrence, which used an alternating voltage whose frequency was adjusted so that each alternation added yet another, fairly small contribution to the energy of a particle, until a large total was reached. (A note about the cyclotron appeared in *Discovery*, October 1944, p. 290, and an article on it by A. K. Solomon was printed in July 1939, p. 331.)

By the use of fast particles a great variety of nuclear changes could be produced. As one example we may take the one which led to the discovery of the neutron by Chadwick after Bothe and Becker had noticed that this reaction produced a highly penetrating radiation. If beryllium is bombarded with alpha particles the following reaction takes place:

$${}_4\mathrm{Be}^9 + {}_2\mathrm{He}^4 = {}_6\mathrm{C}^{12} + {}_0\mathrm{n}^1$$

that is, the beryllium nucleus absorbs an alpha particle and subsequently splits up into a carbon nucleus and a neutron. The upper numbers indicate masses in proton units: beryllium, 9; alpha particle, 4; carbon, 12; and neutron, 1; the lower numbers indicate charges on the nuclei in units of the proton charge, i.e. they are atomic numbers (Fig. 4).

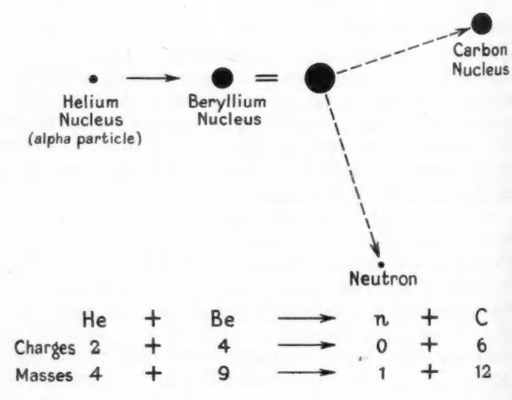


FIG. 4.—An alpha particle (helium nucleus) bombarding a beryllium nucleus is absorbed. The compound nucleus immediately splits up into a neutron and a carbon nucleus.

It will be noticed that both sets of numbers have equal sums on the two sides of the equation; that is, as far as this equation goes, both charge and mass are conserved. Very many other nuclear reactions, produced by bombardment with alpha-particles, protons, or deuterons (the nuclei of the rare hydrogen isotope—"heavy hydrogen"—of mass 2) can be produced. Because the atomic nuclei are so small relative to the whole space occupied by the nucleus and its electrons, the number of successes in this process of random potting at atoms is very small. When a success is scored the fragments may be shot out with very much higher energy than that possessed by the bombarding particle, but, on balance, far more energy has to be put in than can be extracted by such methods. For example, in the reaction given the energy liberated per success is 6 million electron volts. The energy of the alpha-particle is a million electron volts less but the yield per particle "fired" is only 5×10^{-5} electron volts. In addition the positive charge on the nuclei being bombarded tends to repel the positively charged projectiles such as protons and alpha particles, and here the neutron is of importance. By the use of preliminary nuclear reactions, such as that mentioned above, neutrons can be generated, and these have greater effectiveness as bombarding particles, since they have no charge to produce a force tending to divert them from the atomic nuclei at which they are aimed.

By such methods as these it was possible, not only to study nuclear structure and nuclear reactions, but also, especially by the use of the cyclotron, to manufacture new chemical substances in some quantity. Some of these artificial substances were radioactive and have been used extensively in medical and biological investigations, as mentioned in the last number of *Discovery*. These changes are the artificial counterpart of the natural processes of radioactivity already described.

The Source of Nuclear Energy

We have spoken so far of all nuclei of each isotopic species as if the mass were an exact multiple of the mass of the hydrogen atom (more correctly, oxygen, whose mass is approximately 16, is counted as exactly 16 and used as the standard for measuring other atomic masses). This is not quite true. The masses are all very close to, but not exactly, whole numbers. For example, ordinary hydrogen has mass 1·0081; the two stable isotopes of lithium have masses 6·0167 and 7·0180, and the chlorine isotopes have masses 34·893 and 36·980. These small differences in mass are the source of nuclear energy. Suppose, for example, that two hydrogen nuclei and two neutrons were packed together in some way so as to produce a helium nucleus. The mass of the neutron is 1·0089, so that the total mass of the four particles would be 4·0340. But the mass of the helium nucleus is only 4·0039, so that our four particles have a total mass of ·0301 atomic units in excess of what is needed.

Einstein's theory of relativity indicated that material mass and energy were inter-convertible at a standard rate. If, for example, one gram of matter could be annihilated an energy of 9×10^{20} ergs (enough to run a 4,000 horse-power engine continuously for a year) would make its appearance instead. This process of collecting protons and neutrons to form helium nuclei is not a practicable

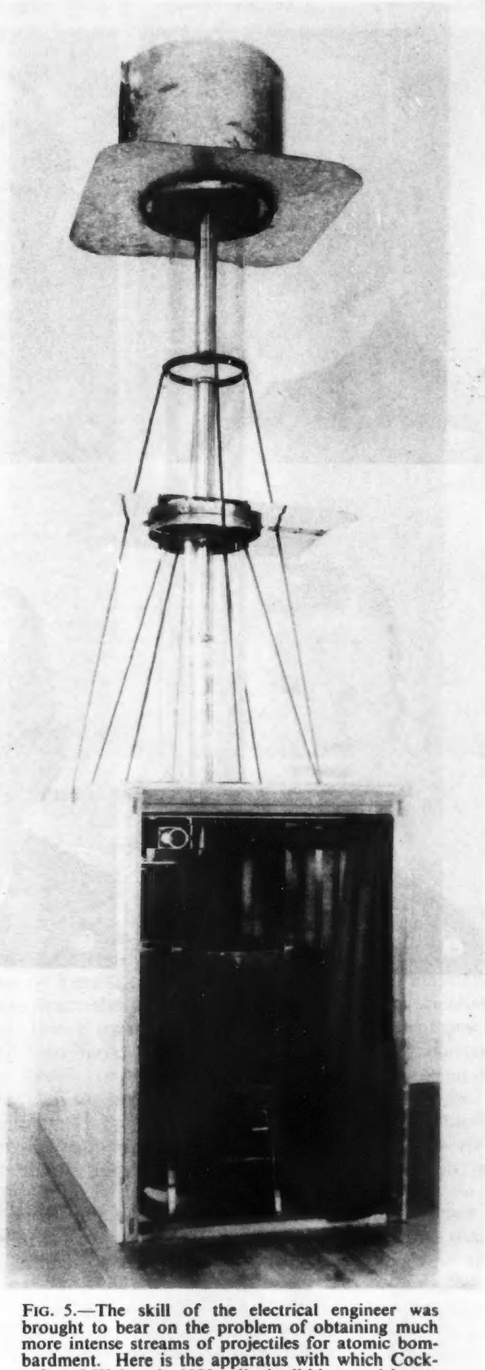
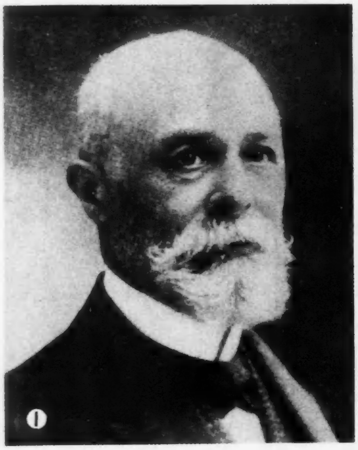


FIG. 5.—The skill of the electrical engineer was brought to bear on the problem of obtaining much more intense streams of projectiles for atomic bombardment. Here is the apparatus with which Cockroft and Walton in 1932 split the lithium and boron atoms. The bombarding particles it generated were protons. (Crown Copyright. From the apparatus in the Science Museum, South Kensington. The metal stay-rods and collars were added to protect the exhibit and formed no part of the original apparatus as used in the Cavendish Laboratory.)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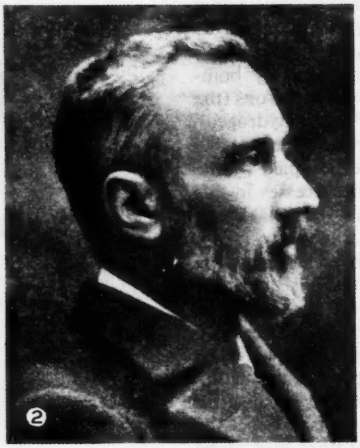
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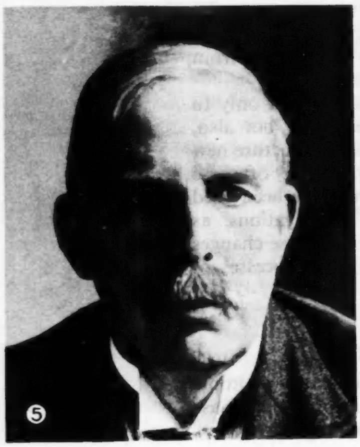
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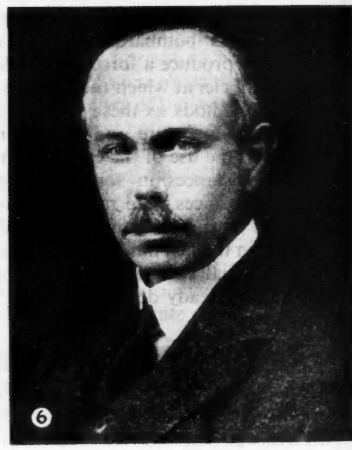
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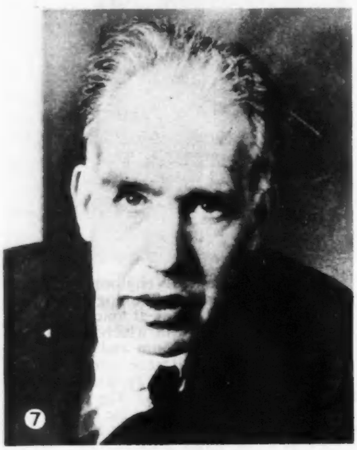
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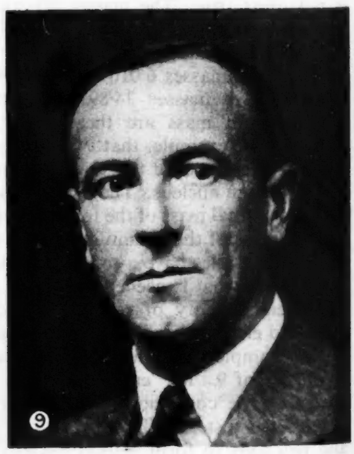
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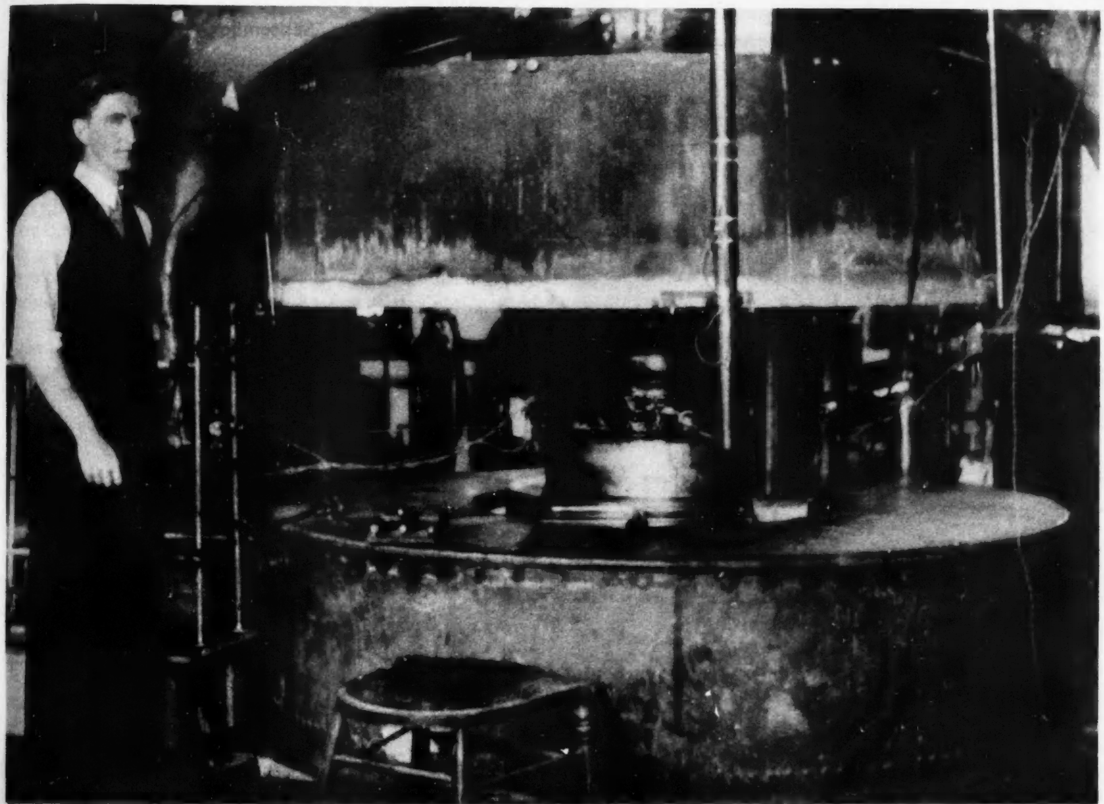

FIG. 6—The first large-scale cyclotron designed by E. O. Lawrence. By 1940 there were 35 cyclotrons in the world, and another twenty were under construction.

one, but, whatever the method by which that nuclear synthesis is realised, the overall energy production would be that indicated by the mass lost. This conversion process of hydrogen into helium does in fact take place indirectly in stars and is the source of stellar energy. The conversion of one gram of hydrogen into helium would release a total energy of about 7×10^{18} ergs—enough energy to run a 30 horse-power engine for a year. These small mass defects are therefore of essential importance in considering the derivation of energy from atomic nuclei.

The nucleus of a stable (non-radioactive) atom must be thought of as a structure in which the forces bonding together the nuclear particles overcome their mutual electrostatic repulsion. It is as if a number of particles were dropped into a small hole in the ground. There they will remain together unless some external force is exerted which will lift one of the particles out of the hole and throw it aside. In radioactive atoms there is more nearly a balance between the bonding and the repulsive forces and the possibility arises, which can be accounted for on the quantum theory, that there will be a small probability of a particle leaking out from the nucleus, thus causing radioactive decay.

Nuclear Fission

A new impetus was given to the study of the structure of heavy nuclei by the discovery in 1939 by Hahn and Strassmann of the phenomenon of nuclear fission. Before that time all nuclear changes had consisted in the removal, either by natural or artificial means, of a small mass and charge from the nucleus. These two German scientists found that if uranium were bombarded with neutrons a much more radical change took place. The nuclei underwent fission, or division into two approximately equal parts, with the liberation of a large quantity of energy.

Actually Hahn and Strassmann did not realise exactly what was happening, and it was Frisch and Meitner who proposed the idea of nuclear fission and realised many of its implications.

Normal uranium has a mass of 238 units, but there is also an isotope, present in only one part in 140, of mass 235; ordinary uranium contains, too, a trace of an isotope of mass 234. U 235 shows the phenomenon of fission not only with high energy neutrons, but in addition with neutrons of very low energy; U 238, on the other hand, exhibits the phenomenon of fission only when the energy

The chain of research that culminated in the development of the atomic bomb is a long one. Here are the portraits of a few of the scientists who contributed links to that chain. (1) Antoine Henri Becquerel; (2) Pierre Curie; (3) Marie Curie; (4) Professor Frederick Soddy; (5) Lord Rutherford; (6) Dr. F. W. Aston; (7) Professor Niels Bohr; (8) Professor Harold C. Urey; (9) Sir James Chadwick, who received special mention in Mr. Churchill's statement on the atomic bomb; technical adviser to the British members of the Combined Policy Committee that integrated the work in the U.S., Britain and Canada.


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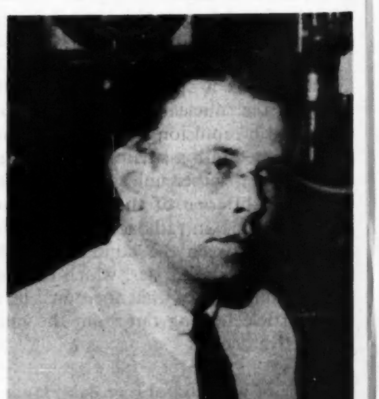
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of the bombarding neutrons is very high. The understanding of the process of nuclear fission was greatly advanced by a theory, published by Bohr and Wheeler in 1939, of the heavy atomic nuclei. This theory was based on certain analogies between the stability of heavy nuclei and the behaviour of a water drop. In a water drop the dissipative forces acting between the constituent molecules are counteracted by the surface tension forces. Very large drops are impossible because the surface tension forces are too feeble, and there is a certain maximum size of drop which can exist permanently. As this size is approached the drop becomes less and less stable, and a small outside disturbance will lead to its disruption into two or more parts. In the same way in heavy nuclei the short range forces tending to bond it together are opposed by the electrostatic repulsions between the constituents, and for certain nuclei a stage is reached when only a small external disturbance is sufficient to cause disruption. Bohr and Wheeler compared the energy associated with the single nucleus, and the energy associated with the same nucleus when disrupted into two or more parts. They found that nuclei of mass greater than 110 were potentially unstable with respect to division into three parts, while for fission of a nucleus of mass 239 into two parts there would be an energy liberation of about 200,000,000 electron volts. The 239 nucleus would be produced by the absorption of a neutron into a U 238 nucleus and this would then undergo fission. An energy liberation of this order would correspond to a mass defect of about 0·2 units, or nearly seven times as great per atom (not per unit mass) as that associated with the synthesis of helium from hydrogen.

The energy liberation associated with the fission of U 235 is of the same order. Other nuclei are also prone to fission, including those of thorium and protoactinium. A further relevant phenomenon is that if U 238 is bombarded with neutrons intermediate in energy between the slow neutrons needed to cause fission in U 235 and the high energy neutrons needed to cause fission in U 238, then a neutron may be absorbed to produce a nucleus of mass 239. This undergoes two stages of beta decay, and consequently two increases in atomic number. The first leads to a substance "neptunium" of atomic number 93 and the second to a stable element, "plutonium", of atomic number 94. Plutonium also exhibits the nuclear fission property, and with neptunium represents the first well attested case of trans-uranium elements, such as had been postulated by the Italian scientist Fermi but not confirmed. (In passing, it may be remarked that the choice of these names seem a little rash, for although there may not be many stable trans-uranium elements the probability seems higher than the probability of the discovery of new planets after which they might be named.)

U 235 and the Atomic Bomb

The fission of U 235 is not a simple process, nor are the details always exactly reproduced. Even in 1939, no less than 16 different nuclei had been identified as products of the fission of uranium and thorium. These fell into two

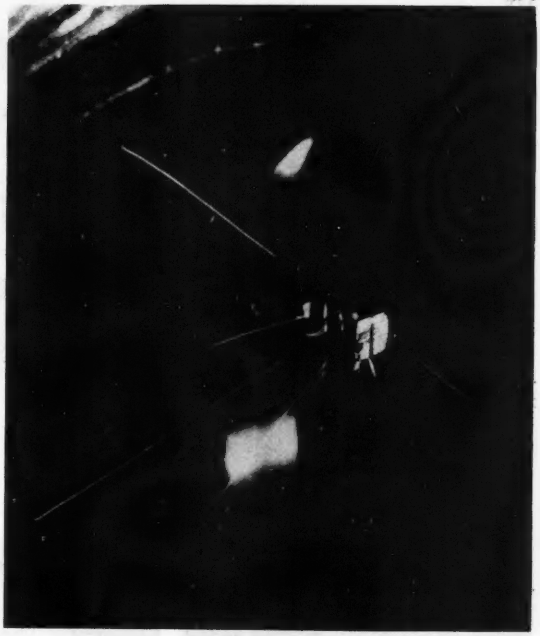

FIG. 7.—The disintegration of lithium under proton bombardment, yielding pairs of α-particles. This cloud chamber photograph is taken from the *Proceedings of the Royal Society* (A, Vol. 141), by permission.

groups: the one group having atomic weight of between 90 and 100, or approximately that of krypton: the other an atomic weight of about 140, or approximately that of xenon. The picture was complicated by the fact that many of these nuclei were unstable and underwent further radioactive decay of a normal type at a variety of rates.

A drastic simplification of the picture is therefore that in nuclear fission the nucleus splits into two parts with a mass ratio of 5:7. In addition it was found that in each process of nuclear fission, an average of something like three neutrons was emitted. The possibility therefore suggested itself that, if one nucleus underwent fission, then the neutrons produced might cause fission in neighbouring nuclei, with the establishment of a chain of processes involving so many nuclei that the whole mass of metal would explode (Fig. 8).

The fission of the first nucleus might be produced either artificially, or might occur naturally as the result of the production of neutrons by cosmic rays. However, if it be supposed that one nucleus has undergone fission then a necessary condition for the establishment of a chain reaction is that at least one of the neutrons produced must be absorbed within the same mass of metal. It is therefore clear a certain minimum quantity of U 235 is necessary for the that production of an atomic bomb, that size being determined by the fact that the metal mass must absorb an appreciable proportion of its own neutrons. Sir Charles Darwin, in his broadcast talk, expressed the matter by saying, "To make an explosion, you therefore take two pieces, each of

(10) PROFESSOR J. D. COCKROFT, succeeded Dr. Halban as director of the slow neutron research at Montreal; (11) DR. E. T. S. WALTON who, with Cockroft, split the lithium atom in 1932, the first time that such a transmutation had been achieved without the use of radioactive products; (12) PROFESSOR P. M. S. BLACKETT; (13) PROFESSOR JEAN-FREDERIC JOLIOT and (14) his wife, IRENE CURIE-JOLIOT, daughter of Marie Curie; (15) ENRICO FERMI; (16) OTTO HAHN; (17) LISE MEITNER; (18) PROFESSOR E. O. LAWRENCE.


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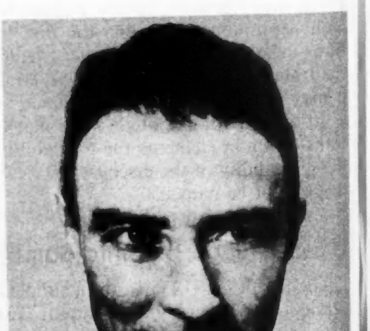
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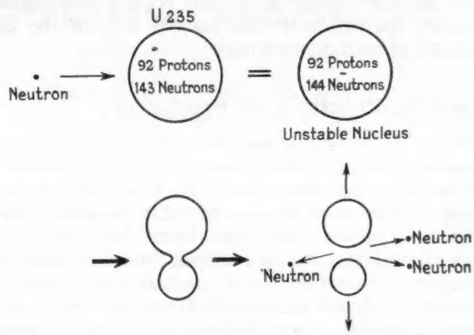
which is too small to explode by itself, and suddenly put them together. The combined mass is then big enough to trap the neutrons."

The various possibilities of producing a chain reaction as far as uranium is concerned would seem to be (*a*) the utilisation of fast neutrons in U 238, (*b*) the utilisation of fast neutrons with U 235 and (*c*) the utilisation of slow neutrons with U 235. The possibilities of (*a*) and (*c*) were discussed by Dr. O. R. Frisch in 1939 (Chemical Society Annual Report) who referred to a calculation that in case (*a*) the uranium mass must have a diameter of about 9 feet and contain 40 tons of uranium oxide. Case (*c*) was rejected as a military possibility because, even if the reaction could be made to work, it would be so slow that the bomb casing would be dispersed, and the process terminated, before any considerable liberation of energy had taken place. In order to make such a process work it would be necessary to slow down the neutrons produced in early fissions so as to allow them to cause further slow neutron fission in other U 235 nuclei. A suggested method for doing this was to use heavy water mixed with uranium: the deuterons would interact with the neutrons and cause a rapid loss of energy and not too many removals of neutrons by capture by deuterons. Frisch referred to the possible use of such a reaction for the controlled production of energy, and mentioned the suggestion that a tractable form of reaction might be secured by mixing a cadmium compound with the uranium–heavy water mixture. At that time he considered that such a slow neutron reaction would probably not be a serious competitor with other forms of energy, owing to the high cost of separation of the U235 isotope. In this connection one may recall Mr. Churchill's reference to heavy water as "one element in a possible process".

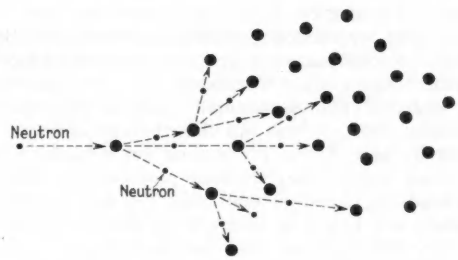
The Stationery Office publication *Statements Relating to the Atomic Bomb* which is, quite understandably, not as explicit at certain points as an ordinary scientific publication would have been, commits itself to the following: *It was realised that ordinary uranium would not be suitable and even if a fast chain reaction could be realised with it a very large quantity of metal would be required. On the other hand, the isotope* U 235 *if it could be separated, offered great possibilities. It seemed that the amount required to make a bomb would not be very large, certainly between one and a hundred kilograms, and rough calculations of the energy released shows that the explosion of such a bomb might be equivalent to many thousands of tons of T.N.T.*

From this, one may presumably infer that the actual process used is a fast neutron chain reaction in U 235.

As may be expected, there are certain differences in clarity of exposition between the official statements on the atomic bomb and an ordinary scientific article. In the official publication mentioned there are references to the use of heavy water (the combination of deuterium, the heavy isotope of hydrogen, with oxygen) and other media for "slowing down" the neutrons. The exact relevance of the references is not clear, but if the energy liberated



A U 235 nucleus absorbs a neutron. The compound nucleus is unstable and splits into two approximately equal parts with the emission of a small number of neutrons.



Chain reaction in a large mass of U 235 started off by a neutron which causes fission of one nucleus.

FIG. 8—NUCLEAR FISSION OF URANIUM 235

when U 235 undergoes fission is of the order of 200,000,000 electron volts, and if this energy is more or less equally shared between the two nuclear fragments and the secondary neutrons produced, then it seems as if the neutrons will be too energetic to produce the further slow neutron fission discussed earlier in the publication. On the other hand, the relevance of these references may be in connection with a possible slowed-down version of the chain reaction for controlled production of energy. We can probably do no better than to accept Mr. Churchill's remark that heavy water was "one element in a possible process". The usefulness of deuterium in its form of heavy water as a slowing-down medium is that interactions between neutrons and deuterons lead to a rapid redistribution of energy and, in addition, there is only a very small probability of the removal of neutrons from the system through capture by deuterons.

What can be said for certain is that the atomic bomb liberates energy extremely rapidly by the fission of nuclei

(19) SIR GEORGE THOMSON, chairman of the committee set up in 1940 under the Air Ministry to examine the feasibility of producing an atomic bomb before the end of the war; (20) DR. F. E. SIMON, directed research into isotope separation by gaseous diffusion at the Clarendon Laboratory, Oxford; (21) PROFESSOR NORMAN FEATHER, directed atomic bomb research at the Cavendish Laboratory, Cambridge; (22) PROFESSOR M. L. E. OLIPHANT, whose research team at Birmingham was eventually moved to Berkeley, California, to assist Professor Lawrence's group on electromagnetic separation of U 235; (23) PROFESSOR G. B. PEGRAM, who visited Britain in November 1941 with Professor Urey, to organise liaison between British and American atomic bomb researchers; (24) LORD CHERWELL, member of Sir John Anderson's committee, personal scientific adviser to Mr. Churchill when Prime Minister; (25) SIR EDWARD APPLETON, who, as secretary of the D.S.I.R., held ultimate responsibility for the work of his department's "Tube Alloys" Division; (26) PROFESSOR R. PEIERLS; (27) DR. J. R. OPPENHEIMER.

of the uranium isotope U235, this being a chain reaction in which the fission of one nucleus sets off the same processes in neighbouring nuclei.

Scientific Problems of Production

The scientific programmes have been directed first to the establishment of the necessary nuclear data and the calculation of the critical size of the bomb and, secondly, to the production of the isotope U235 in quantity. Both these programmes have now been described. Other practical problems, as, for example, those concerned with the construction of the bomb, perfecting the mechanism of setting it off, and securing conditions in which as much energy as possible should be liberated before the reacting mass was dispersed so far as to bring the process to an end, must have been solved though none but the scantiest details have so far been given.

The nuclear research involved must represent a vast extension of programmes of known type, and this extension has probably advanced knowledge of the nucleus very far indeed. The problem of the separation of isotopes, on the other hand, represented something completely new. Before the war isotopes had been separated, but only on the most minute scale, whereas to produce U235 in quantities of the order of pounds required a major industrial and technical effort. It was not that the methods were new but that now methods operating on a scale millions of times greater than anything previously known were required. Posssible methods were the gaseous diffusion method and the electro-magnetic method, both mentioned in the White Paper. The gaseous diffusion method depends on the slightly more rapid diffusion of lighter isotopes through a porous barrier: the electro-magnetic method is in principle that used in the mass spectrograph. The translation of these methods, difficult enough in the laboratory, to the industrial scale will stagger the imagination of any scientist and must have involved problems of the utmost difficulty. Even to separate such distinct isotopes as chlorine 35 and 37 would be bad enough but to separate U235 and U238 was a problem of a still higher order of difficulty.

This problem, though less spectacular, ranked as of equal importance with the problems of nuclear structure in the realisation of the bomb. The official publication devotes considerable space to the history of the development of the necessary organisations and plant and its transference to the United States where freedom from bombing was assured and man-power and material more readily available. Calculations of the blast effect likely to be produced must have led into entirely new scientific territory. It has been stated that when the bomb exploded the mass reached a temperature of several million degrees. It is easy to see how this comes about. At each temperature of matter there is a certain amount of energy associated with each particle of the gas. If the energy liberation were 200,000,000 electron volts and this were shared among five particles these would have the same energy as that associated with the fantastic temperature of 200,000 million degrees. However, it is not to be suggested that this corresponds to the temperature actually reached. In a minute fraction of a second each nucleus which had undergone fission would share its energy with other neighbouring atoms. For example, one presumes that the U235 was not pure, but was still contaminated with a large proportion of U238. These and the atoms of the air, earth, bomb structure, and so on, would rapidly take up energy, so that the energy share-out might take place over a large number of other atoms, with a consequent proportional reduction in temperature. Even so, conditions must have been very much as if a few pounds of the material from the interior of a star had been materialised suddenly on the earth, with the production not only of a violent blast wave from the heated air, but also the emission of a tremendous amount of extremely short-wave X-rays, which although absorbed by air, must have contributed to a considerable extent to the destruction experienced at moderate ranges from the seat of explosion.

REFERENCES

IN addition to the references to previous issues of DISCOVERY, the following list of references may be found useful. The White Paper is *Statements Relating to the Atomic Bomb* (Stationary Office, price 4*d*.). Two important original papers are those of Hahn and Strassmann, *Naturwissenschaft*, 1939, Vol. 27, p. 11, and of Bohr and Wheeler, *Physical Review*, 1939, Vol. 56, p. 426.

Useful summaries at an advanced level are to be found in the *Annual Reports of the Chemical Society* (1938—the meson; 1939—nuclear fission by Frisch, and nuclear theory by Peierls; 1940—nuclear fission and transuranic elements, also by Frisch).

General accounts of atomic structure also at a fairly advanced level are to be found in such works as *Atoms, Molecules and Quanta* by Ruark and Urey. *Atomic Nuclei and Nuclear Transformations* by Gamow: *Mass Spectra and Isotopes* (2nd edition, 1942) by Aston and *Radiations from Radioactive Substances* by Rutherford, Chadwick and Ellis.

More elementary accounts are *The Interpretation of the Atom* by Soddy, and *Why Smash Atoms?* by A. K. Solomon.

A discussion of nuclear changes and stellar energy production is to be found in *Nature*, 1939, Vol. 144, pp. 575 and 620 by Gamow and a popular account of atomic structure from this point of view, including a discussion of nuclear fission, is Gamow's *Birth and Death of the Sun*, Macmillan, 1941.

Considerable historical interest now attaches to the comments on nuclear fission by Frisch, Bohr, Joliot, Feather and Magnan published in 1939 in Vol. 143 of *Nature*.

PROGRESS OF SCIENCE—*continued from p.* 262.

the discovery, or more correctly, the creation, of two new chemical elements neptunium and plutonium: the extension of knowledge on the state of the nucleus, and the development of a theory of nuclear fission in heavy atoms.

At the same time, quite remarkable advances have been made in applied science and technology. The scale on which the processes of isotope separation have been carried out must have been staggering. The effect on the chemical industry is likely to be interesting. Before the war it would have seemed madness to try to separate in quantity isotopes differing in mass by only one part in eighty. But now that it has been demonstrated that it can be done, it may well be that separation of isotopes of other elements will become a feature of chemical industry.

The Greatest Scientific Gamble

MANY months ago questions used to be asked in the House of Commons about a mysterious war research project on which some £16,000,000 was supposed to have been spent. The Government spokesmen successfully evaded the questions without creating any untoward interest in the mystery. Such curiosity as may have been aroused received no satisfaction until this August after the first atomic bomb had been dropped. By that time, according to President Truman's statement, 2,000,000,000 dollars had been spent on this atomic bomb project—"the greatest scientific gamble in history."

The collection of the fundamental facts that gave the clues as to possible ways of releasing energy from the atomic nucleus was an international affair. To that store of knowledge scientists of all nations contributed, and this international aspect is well brought out in Dr. Evans's article. The war-time researches that culminated in the bombs that fell on Hiroshima and Nagasaki had a similar international character, though there was one essential difference—the results of the war research were kept secret.

The Thomson Committee

According to the press statement issued by the Department of Scientific and Industrial Research (this statement is included in the official pamphlet, *Statements Relating to the Atomic Bomb*), it was at the beginning of 1940 that the attention of the British Government was called to the possibility of producing a military weapon of unprecedented power if a chain reaction with fast neutrons disrupting the nucleus of the uranium 235 atom could be realised. This suggestion was put forward to the Government independently by Dr. Frisch and Professor Peierls, both of Birmingham University, and Professor Chadwick of Liverpool. In April 1940 a committee of scientists was set up, under the chairmanship of Sir George Thomson, to examine the whole problem.

The committee was instructed to report whether the chances of producing effective atomic bombs in time for use during the war were sufficient to warrant the diversion of skill and labour that any such project would entail. Data was needed before any estimate could be made as to the size of bomb that might be produced; without that estimate there was nothing on which to base an assessment of the scale of industrial effort that would be required to produce the necessary materials. The collection of such data had already been begun by Professor Chadwick's team and this work was now accelerated, with Dr. Frisch and Dr. Rotblat assisting Professor Chadwick as his senior collaborators. As their work progressed new problems were thrown up, and another research team, at Cambridge and under the direction of Dr. Feather and Dr. Bretscher, was brought into this line of investigation. With experimental data provided by these two teams it became possible for Professor Peierls, assisted by Dr. Fuchs and others, to calculate the critical size of the bomb; they also calculated the amount of energy likely to be released and considered how it might be increased.

Another urgent problem was to devise a large-scale method of separating uranium 235 from ordinary uranium. Sir George Thomson's committee selected the gaseous diffusion technique as being likely to prove the most economical in manpower and industrial plant. Research on the process was taken up by a team of workers at the Clarendon Laboratory headed by Dr. F. E. Simon. Assistance on theoretical aspects was given by Professor Peierls's group, while on the chemical side contributions were made by Professor W. N. Haworth's group at Birmingham University. Some experimental work was also started at the Imperial College of Science and Technology, South Kensington. On the many technical questions arising Metropolitan Vickers Electrical Co. and I.C.I. were consulted.

By the early summer of 1941 the committee had decided that an atomic bomb was feasible, and reported this conclusion, together with a fair estimate of the industrial effort that would be needed, to the Scientific Advisory Committee of the War Cabinet.

The Thomson committee also considered one other aspect of uranium fission. That was the possibility of finding out how a mixture of uranium and some slowing-down medium might lead to a neutron chain-reaction wherein the release of energy would be obtained in a controlled way. This aspect was investigated by Dr. Halban and Dr. Kowarski, two French physicists who had come to Britain at the time of the fall of France, bringing with them the 165 litres of heavy water—practically the world stock of this substance—which the French Government had bought from the Norsk Hydro Co. just before the invasion of Norway. By December 1940 they had produced strong evidence that using uranium oxide or uranium metal with heavy water as the slowing-down medium a slow neutron fission chain-reaction would be realised; no more than a few tons of heavy water would be required, they estimated. The scientific committee decided however that, though this work had great interest as a potential means of producing power, this particular application was not likely to be developed before the war ended. But the slow neutron work was recognised to have a bearing on the military project, in that it might yield plutonium to replace uranium 235 in an atomic bomb.

"Urgent and Secret"

Following the Cabinet's Scientific Advisory Committee's endorsement of the Thomson committee's view on the importance of attempting to produce atomic bombs, Sir John Anderson was asked by the Prime Minister, in September 1941, to undertake supervision of the atomic bomb project, now given the highest priority as a project of great urgency and secrecy. Sir John then appointed a Consultative Committee including the chairman of the Cabinet's Scientific Advisory Committee, Sir Henry Dale, Sir Edward Appleton, and Lord Cherwell.

To develop the project a new division was formed within the D.S.I.R. in November 1941, its purpose camouflaged under the name of "Directorate of Tube

Alloys". Mr. W. A. Akers was released from I.C.I. to direct the division, with Mr. M. W. Perrin as his assistant. A technical committee was set up to advise him, and this was composed of scientists directing work already in progress—Professor Chadwick, Professor Peierls, Dr. Halban, Dr. Simon, Dr. Slade; later it was joined by Sir Charles Darwin, Professor Cockroft, Professor Oliphant, Professor Feather.

In October 1941 President Roosevelt wrote to Mr. Churchill stressing the necessity of co-ordinating the British and American efforts, and this co-ordination was effected without delay. To complete the arrangements for rapid exchange of all information Professor Urey and Professor Pegram of Columbia University visited this country, and a return visit to the States was paid by a British mission. By this time all American work was co-ordinated by the Office of Scientific Research and Development, whose director, Dr. Vannevar Bush, thenceforward reported every major item of atomic bomb progress direct to the President.

It now became clear that the scale upon which the research and development work could be undertaken here must be far smaller than in America. In the summer of 1942, the decision was taken that the large-scale production plants should be in the United States, and so began the construction of two vast plants—located respectively at Oak Ridge, near Knoxville, Tennessee, and Richland, near Pasco, Washington—while a special laboratory was built at Santa Fe, New Mexico. (This laboratory came under the direction of Dr. J. R. Oppenheimer, to whom the U.S. Secretary of War paid special tribute in his statement of August 7.)

Research in Britain was now concentrated on certain specific problems. The teams engaged in determining nuclear physical data under Professor Chadwick's direction were strengthened, and small additional programmes of research started at Bristol and Manchester Universities. Slow neutron work continued at Cambridge under Dr. Halban and Dr. Kowarski until its transfer to Montreal. Professor Peierls's team continued their work, which came under Dr. A. H. Wilson's direction when Peierls went to America. Professor Dirac also assisted in this theoretical investigation. Gaseous diffusion research remained the concern of Dr. Simon and his group. Pilot plant work on this process was turned over to Metropolitan Vickers Electrical Co., and to the Billingham Division of I.C.I. working in conjunction with the Metals Division. Other firms were brought in here, including Mond Nickel, while research on the properties of uranium metal was undertaken by a number of laboratories including the National Physical Laboratory, the British Non-Ferrous Metals Research Association and I.C.I.'s Alkali Division; university work in this direction was done at Oxford, Cambridge and Birmingham. Designs for heavy water plant were drawn up by I.C.I.'s Billingham Division.

In America great strides had been made at the University of California by Professor E. O. Lawrence's team in the conversion of the mass spectograph, the instrument used for separating isotopes on a laboratory scale, into an industrial scale apparatus. At one stage it was intended to do similar work in Britain under Professor Oliphant at Birmingham. But Professor Oliphant was busy with other work, and the project had to be abandoned, Professor Oliphant's team being moved to the United States. (Work on this problem was eventually started here in March 1945, three British electrical equipment firms—B.T.H., G.E.C. and Metropolitan Vickers Electrical Co.—participating in it.) A reasonable deduction from the official statements is that both gaseous diffusion and electro-magnetic methods were used to concentrate the uranium 235.

It should be recorded that all "tube alloy" research contracts put out by the British Government leave the Government in exclusive control of all discoveries and inventions emanating from the many different lines of research, whether carried out in university or industrial laboratories.

This very condensed summary of the organisation of the atomic bomb project would be inadequate without a reference to the Canadian contribution. Slow neutron work was eventually transferred from Cambridge to Canada. To accommodate it a special laboratory was set up within the National Research Council in 1943. According to the statement of the Canadian Minister of Munitions, in that laboratory in Montreal, there is now a staff of about 350—the list of research scientists there numbers 140; over half are Canadian, and others were sent there by the British Government and included Dr. Halban and Dr. Kowarski. Several of the National Research Council's divisions have also contributed to atomic bomb research, and there have also been teams working at McMaster, Toronto and McGill Universities. In Canada all sources and supplies of uranium early came under the control of the Government whose geologists have carried out new surveys in search of uranium ores.

Integration of American, Canadian and British atomic bomb research was achieved through a Combined Policy Committee under the chairmanship of the U.S. Secretary of War. This Policy Committee was advised by a technical sub-committee composed of Sir James Chadwick, Major General L. R. Groves (who supervised the "Manhattan Engineer District", the name camouflaging the U.S. atomic bomb project), and the president of the Canadian National Research Council, Dr. C. J. Mackenzie.

THE British Government has appointed the following committee to advise it on questions of atomic energy, both for industrial and military purposes: Sir Alexander Cadogan (Foreign Office), Field-Marshal Sir Alan Brooke (Chief of the Imperial Staff), Sir Alan Barlow (Treasury), Sir Edward Appleton (Secretary, Department of Scientific and Industrial Research), Sir Henry Dale, Professor P. M. S. Blackett, Sir James Chadwick, Sir George Thomson. A similar committee has been set up by the United States Government.

The British Bats

BRIAN VESEY-FITZGERALD, F.L.S.

An enormous number of people in this country can distinguish at least half a dozen common birds and name them correctly. Even the most hidebound and disinterested city dweller knows the sparrow and the pigeon and never confuses the two, while there are certainly hundreds of amateur naturalists who can name correctly all the birds they are likely to see upon an afternoon's walk. A bat, however, is simply a bat. If that is true of the vast majority of countrymen—and it is true—it is, unfortunately, no less true of the vast majority of field naturalists. Even those expert naturalists who can place the species correctly from a glance at a skin are all too frequently quite unable to distinguish one from another on the wing. Very, very few people can distinguish between bats on the wing, much less name them correctly. A bat remains a bat irrespective of species. And yet there are twelve species native to the British Isles and most of them are common. Furthermore, they differ widely from each other in their habits, modes of flight, flight calls, and even in many cases in size. There is really no more excuse for lumping them all together as bats than there would be for calling all little brown birds sparrows.

I think this widespread inability to distinguish one kind of bat from another on the wing springs mainly from lack of interest. And this lack of interest in turn springs from laziness. Birds are comparatively easy creatures to watch: bats are not. They are crepuscular, and they live, as a rule, in rather inaccessible places. In colour they are all much alike, and their rather erratic flight makes them anything but easy to follow in the failing light. I have found that the study of bats—and I have been studying them consistently for upwards of twenty years (indeed I have had one or more bats in captivity every year since I was thirteen)—involves a fair amount of discomfort and the expenditure of a great deal of patience, but it is all very well worth while for I do not think there are any more interesting creatures in all our fauna.

Bats are flying mammals, the arms having changed into wings. A membrane stretches between each of the long fingers and bones of the hand, but the short thumb is free from the wrist and is armed with a claw. The second finger is short and forms the front of the wing, and the third finger is the longest. From the fifth finger the membrane stretches along the arm to the armpit and thence along the flank and leg to the ankle, the exact point on the leg at which it ends varying with the different species. Another membrane (called the interfemoral membrane) stretches between the legs and the tail, and is supported by a spur of bone (called the calcar) from the heel along or near to its edge. The legs are much smaller than the arms, and are twisted by the shape of the hip bones so that the knees point backwards. Each of the five small toes is clawed. Bats are not blind, but the eyes are very small, and the sight is very poor. Hearing is very keen for high-pitched notes, but bats appear to be completely deaf to low-pitched sounds, no matter how loud they may be. I have found that my captive bats will respond at once to the tearing of a thin sheet of paper, but they are quite unaware of the sound of a big dinner gong, even when beaten fiercely immediately below them. But to make up for this rather specialised form of hearing and their very inadequate powers of sight, they have truly remarkable powers of "feeling", which enable them to avoid obstacles in the dark or when they are blindfolded. This additional sense* is not yet properly understood by the scientist, but it seems probable that it is connected with the wing membranes and the "earlets" or "nose-leaves". The hair is long and silky, with an undercoat of fine wool, and is always kept immaculately clean by means of the tongue. Bats wash themselves as frequently and as diligently as cats.

The young of all our bats (no British bat has more than one young one in a year) are born in summer—round about Midsummer Day would be a good average date—and are quite helpless at birth. They are carried around by the mother until they get too heavy and are then left hanging in the den while she goes out hunting. Towards the middle of August they begin to fly and fend for themselves. Apparently they fly by instinct. Most people have seen young birds being taught to fly: no one has ever seen a young bat being taught to fly. The mating season, in all our bats, is in autumn, just before hibernation, usually in late September or early October. There is no courtship or pairing. Bats are promiscuous. All our species are gregarious, and all hibernate. Generally they leave their summer retreats and resort to caves or some other suitable situation for this purpose, and there they hang by the feet, upside down, with wings wrapped around body, fast asleep. Their temperature drops to that of their surroundings and their breathing becomes very light and very slow. It is not always easy to distinguish a hibernating bat from a dead bat. On warm winter days some individuals wake and come out to hunt for food, but in a cold winter hibernation is very sound, and with one possible (but by no means certain) exception all our bats may safely be called determined hibernators. In summer most bats sleep throughout the day and most of the night, coming out to hawk for food only in the evening and at dawn. One or two species fly off and on through the night, but I think this is a characteristic of individuals in a species rather than of the species as a whole. The duration of the hunting flight differs, of course, with the various species. All the British bats are wholly insectivorous, and of great value to man.

Our twelve species fall into two distinct families—the *Vespertilionidae*—the "earlet" bats, and the *Rhinolophidae*—the "nose-leaf" or "horseshoe", bats. The former, by far the most numerous both in individuals and in species, have a well-developed "earlet" (the tragus) which represents the small prominence in front of the human ear, and the bones around the shoulders are not

* A note on some American experiments that suggest bats may "echo-sound" their environment supersonically appeared in Discovery, September, 1943, p. 264.

Lesser Horseshoe Bat

The Noctule

fused. The latter, comprising but two species, have a most extraordinary development on the face roughly shaped like a horseshoe but resembling a cluster of rather withered leaves. This excrescence is a sense organ, and since these bats have not got the tragus common to all the others it probably serves the same little understood function as that organ. Horseshoe bats have a solid ring of bone round the body at the shoulder which is formed by the fusion of the first two ribs with the backbone and the breastbone.

So little work has been done on these British bats that we do not even know their distribution in England properly. Bechstein's bat, for example, has (according to the books) been recorded from only three places—the Isle of Wight, the New Forest, and a single example from Henley-on-Thames. I am by no means sure that it is as rare as all that, and the example from Henley-on-Thames seems to indicate a wider distribution. I have watched this bat in the New Forest, and just before the war I watched others in the Harewood Forest district, but I have not been able to get to the place again since. Similarly, Leisler's bat is officially regarded as occurring only in the Avon valley in Warwickshire, in one or two restricted localities in Cheshire, and still more locally in Yorkshire. That is the distribution given in Barret-Hamilton (the information was acquired in and prior to 1910) and it has been slavishly followed by one compiler of handbooks to our fauna after another ever since. Recently a friend of mine, who is thoroughly knowledgeable about bats, has found it far beyond its accepted range in Yorkshire; it has been found, too, in Somerset, and I have found it in the Punch-bowl at Hindhead and in the Meon Valley in Hampshire, where it is indeed fairly frequent. It is very likely that even those people in the south of England who are well acquainted with the Noctules on the wing (and I fear there are not very many) mistake Leisler's for that bat, thinking it a small immature specimen. But for so long as the majority of our naturalists are content to lump all bats together, for so long will our knowledge of their distribution remain vague and incomplete. It is, in fact, high time we ceased to regard the data on distribution given by Barret-Hamilton as final, and commenced to compile county lists of the Cheiroptera in the excellent and thorough manner of our county lists of birds. Only thus will our knowledge of their distribution be increased.

I have not space in this article to go fully into the differences in modes of flight and flight calls, but a brief description of each of our twelve species—eleven of which I have kept in captivity—may be useful to those contemplating taking a further interest in our bats.

THE NOCTULE (*Nyctalus noctula*). This is the largest of our British bats. There is a good deal of variation in size, but this is rarely noticeable in flight. The wing span is said to range from 13 to 15 inches. The largest specimen I have examined personally has a wing span of 14⅛ inches, but I have also had an adult female in captivity which measured barely 12½ inches. The Noctule flies fast and, for a bat, remarkably straight. The flight is not altogether unlike that of a swift, and the animal when hawking can hold its own very well with the bird. Generally speaking, it flies high (often out of gunshot range) but on nights of cold wind it flies low—as low as 10 feet—and usually in

Daubenton's Bat

The Barbastelle

shelter. It is capable of long and sustained flight, and I am sure it covers a great distance in the summer, returning in the autumn to its native hibernaculum. It seems probable that there is some reinforcement of our native population from France. A direct flight across the Channel is certainly well within the powers of the species. The Noctule is primarily a woodland bat. During flight it squeals constantly. Translating animal sounds into human words is never a satisfactory process since each man hears sounds somewhat differently. The cry of the Noctule sounds to me like *wyeee, wyeee, wyeee, wyeee*, very shrill and high-pitched.

LEISLER'S BAT (*N. Leisleri*). Very like the Noctule, but much smaller and less thickly built. The wing span is rarely as much as 11 inches. The flight is fast but erratic, *and the wings come well below the body on the downward stroke*, seeming almost to meet underneath. It generally flies at a low altitude, rarely in excess of 30 feet, and is more susceptible to wind than its larger relative. It, too, is a woodland bat. It is much less noisy on the wing and the cry is more of a chatter—*tack, tack, tack*, but very high-pitched. Whereas the Noctule prefers to hibernate in buildings, I have found Leisler's bat hibernating in trees.

THE SEROTINE (*Eptesicus serotinus*). A large bat, almost as large as the Noctule. I have had specimens with wing spans in excess of 14 inches, but I have also had them with spans of only 12 inches. The Serotine lives as a rule in buildings, but prefers to hawk in the neighbourhood of trees. The flight is slow and wavery, and generally rather low to begin with but gets higher as the light fails. This is the bat that does sudden headlong dives, apparently completely out of control. The dives are due to the capture of some large insect and the necessity of pouching it in the interfemoral membrane prior to eating it. On the wing it is normally silent. The only sound I have heard it make in flight, and that has been but rarely, has been a high-pitched squeak of the sort dolls used to make in the days of my childhood. This bat can and does bite. I have been bitten quite severely more than once. It is also of a quarrelsome and indeed belligerent nature. One in my possession killed a Pipistrelle, afterwards attempting to copulate with the corpse. When handled it chatters with rage.

THE PIPISTRELLE (*Pipistrellus pipistrellus*). This is our smallest bat. A very good case could be made out for its being our smallest mammal. The wing span very rarely attains 8 inches. Very common everywhere, except, apparently, in Staffordshire. The flight is erratic and rarely above 20 feet, but it is fast and capable. Drinks on the wing. It is very chatty in flight, uttering constantly a series of short *tick-tick, tick-tick*, very high-pitched. Hibernation is less prolonged than in any other British species. Very variable in colour, white or albino examples turning up frequently. In Hampshire examples with a distinct white or whitish border on the hinder part of the wing membrane are not at all uncommon, and one occasionally finds whole colonies marked in this way.

THE LONG-EARED BAT (*Plecotus auritus*). Very easily recognisable because of its very long ears, which are capable of independent movement. The wing span is 10–10½ inches and is remarkably constant. In direct flight

the ears are held straight in front of the body. A high-pitched chirrup—a chicken-like sound—is uttered almost continually during flight. When moving from one hunting ground to another the flight is fast and direct, and is usually conducted at only a few inches from the ground, but when feeding it is moth-like, and there is a good deal of very adept hovering. The food is not as a rule taken on the wing as with most other bats, but is picked from the leaves of trees and bushes. The Long-Eared Bat makes an excellent, cheerful and docile pet, and can be trained to answer calls. But it cannot be kept in the company of other bats as it is extremely quarrelsome. When first handled it complains in a querulous child-like tone, but if kept in captivity for any length of time it grows to appreciate handling and comes to be stroked and petted. I used to carry one around with me in my pocket and used to let it out in my study and in my office for exercise. It once took itself for a little exercise round a fashionable restaurant at lunch-time, causing a considerable sensation among the female diners!

DAUBENTON'S BAT (*Myotis Daubentonii*). Also known as the Water Bat. A sturdily built bat with a wing span of 10–11 inches. It is very common along all our rivers, streams and ponds. Occurs around the lake in St. James's Park and by the Serpentine, and also along the Regent's Park Canal. In summer frequents old trees, but in winter hibernates in buildings. The flight over the water is low and a good deal faster than it appears; the surface is broken to take floating insects and this is the bat that is sometimes taken on fishermen's flies. On the wing it chirps frequently but not continually. The sound is lower-pitched than in most bats and is soft and not unmusical. To my ears it sounds like *po-ep, po-ep*.

NATTERER'S BAT (*M. nattereri*). This bat is also found in the vicinity of water, but is definitely not a water bat. Very similar to Daubenton's bat in build, but with a wing span of 11–12 inches. There can be no confusion with Daubenton's bat, however, because in flight the wings of Natterer's Bat appear light and *the tail is carried straight out behind*. Also it is a noisy bat and makes loud squeaks that can be heard by anyone with normal hearing. It is in fact one of the easiest of all bats to recognise on the wing. Hibernates in buildings but hunts always in the neighbourhood of trees, picking its prey, as does the Long-Eared, from the leaves. It will also hover over water. The flight is slow and steady.

THE WHISKERED BAT (*M. mysticanus*). This very common bat is only a little bigger than the Pipistrelle, for which it is probably often mistaken; but there is no excuse for confusing the two on the wing. Its wing span rarely exceeds 8½ inches. In flight the Whiskered Bat shows a white under-body. In flight the Pipistrelle is noisy: the Whiskered is silent (I have never heard a Whiskered Bat make a sound on the wing). The flight of the Pipistrelle is erratic: the flight of the Whiskered is steady. The Pipistrelle takes its food on the wing: the Whiskered takes its from leaves, posts and so on. It is particularly fond of spiders. Unlike most bats it grunts rather than squeaks when handled. Quickly becomes tame and affectionate when kept in captivity.

BECHSTEIN'S BAT (*M. Bechsteinii*). This species has not been sufficiently studied to warrant even the briefest of exact descriptions. The wing span of the only one I have handled was approximately 11½ inches. I captured this one in the New Forest near Burley. It was active, quarrelsome and noisy, and unfortunately it escaped during the night. The flight of the few I have watched has been ponderous and slow and conducted only a few feet (three or four, no more) from the ground. The small colony I found near Burley lived in a hole in a beech tree. They hawked round beech trees and round apple trees in a neighbouring garden. Those I watched in the Harewood Forest area also hawked round beech trees and apple trees. There may be some ecological significance in this. The ears are large and carried well forward. The flight is not erratic.

THE BARBASTELLE (*Barbastella barbastellus*). A black bat, *appearing jet black on the wing*. The wing span is 9½-10 inches, but the bat seems very slender in build when seen in flight. The flight is low and uncertain and silent—I have never heard the Barbastelle make a sound in flight—and is never conducted far from the resting place to which frequent returns are made during the hunting period. It rests during the day in holes, in trees and walls, or in the thatch of buildings or ricks. It hibernates in buildings and is solitary in disposition. The Barbastelle is very difficult to keep in captivity and is very bellicose towards other species. All the ones that I have had have bitten me ferociously, but the bites are not severe. When handled it buzzes like an angry hornet.

THE GREATER HORSESHOE BAT (*Rhinolophus ferrum-equinum insulans*). A large bat with a wing span of 13-14 inches. It is very gregarious and large colonies have been found in caves and buildings. The flight is exceptionally graceful, a compound of sailing and gliding, in the manner of a gull, with quick, rather butterfly-like wing strokes. Almost invariably it flies low, in and out of the undergrowth in woods and so on. On the wing it is silent, and those I have had in captivity have never been talkative. A faint *peep-peep* is uttered occasionally, and seems to be a sign of pleasure. Even when quarrelling the voice is still very soft and faint, but the sound is more like *chicka-chicka*. It is comparatively easy to keep in captivity and soon becomes tame and friendly, but it is by no means easy to keep one alive through the winter, and I have come to the conclusion that they must hibernate in company.

THE LESSER HORSESHOE BAT (*R. hipposideros*). A much smaller edition of the above, the wing span rarely exceeding 8½ inches. The flight is, however, quite different. The sailing and gliding are absent and the wing beats are very quick, much quicker than in any other bat, too quick indeed for the human eye to follow accurately. The voice is low and rather gruff for a bat—*check-check*—and is used on the wing, and there is an extensive vocabulary of small chattering squeaks which are uttered while at rest. Lesser Horseshoe Bats are very susceptible to wind, and do not come out to hawk on nights when the wind is at all blustering or chilly. Personally I have found them very difficult to keep in captivity. They become tame rapidly, but they die on the slightest excuse and sometimes without apparent excuse.

I have deliberately not given any indication as to distribution, since I believe that our present knowledge is too scanty and too inaccurate to be worth repeating. All twelve species occur in Southern England, however.

RADAR—Radio Detection and Ranging—was first known under the cryptic letters "R.D.F."; the term "Radiolocation" came into favour in 1941 after the first public disclosure that we were using this new technique, but this has now been superseded by the word "Radar". The first practical and detailed proposals for locating aircraft by radio were made in 1935 by the author of this article, who is now Scientific Adviser on Telecommunications to the Air Ministry and the Ministry of Aircraft Production.

Radar

SIR ROBERT WATSON-WATT, C.B., F.R.S.

THE greatest difficulties in military operations are to know where and in what strength the enemy is, and what he is going to do next, and to have this information in sufficient time to frustrate his intentions. In mobile warfare there arise difficulties of the same general kind in knowing where you yourself are, and when, if you do certain things, you will arrive at your objective. This general two-fold problem of acquiring and maintaining timely information about the relative positions and rate of change of relative positions of the elements of the two forces has a series of particular cases. These run into greater and greater detail from the general strategic picture to the problem of the weapon aimer, who has to measure or estimate the factors necessary to make his missile occupy the same position, at the same moment, as his target.

The particular problem of the early detection and location of enemy aircraft was thus no new problem when it came up for special attention in the early days of 1935. Many people knew all the difficulties of seeing or hearing aircraft sufficiently early to allow air defence measures to be made effective. The searchlight was an attempt to reduce the uncertainties due to darkness. The acoustic location system was an attempt to use means which were independent of visibility. The searchlight was a poor device because it had not only to search for a needle in a haystack, the range of its search was too short and it had no means of knowing whether it was missing the needle through looking too high, too low, too much to the left or too much to the right. The acoustic system was also very limited in its capabilities because it was subject to meteorological vagaries, because it too was short in effective range (although it could under favourable conditions far outrange the searchlight), and because it was very poor at searching out the information about one aircraft from among the noises due to other aircraft, and from the noises due to steamers and motor cars and the rustling of trees in the wind, and all the other background noises which will go on happening, peace or war.

There was then no fresh need in those first days of 1935, nor did there appear in 1934 any novel means for meeting that need. All the elements of a radio system to meet the need were available well before 1934. Why then did British radar appear in the first months of 1935, as an answer to a long standing military need? There were lots of people who knew the need and lots who had in their minds parts at least of the answer to the need. There were very few people who were in a position to ask the right questions, at the right time, in the right language, of the right people. The revolution of 1935 came because political, military and scientific foresight brought together the people who were qualified to put the question in the right shape, and the people who could put the answer into the right shape, in intimate and continuous contact. As Lord Swinton has recently said:

> There was nothing very novel in calling in scientists; it would indeed have been very odd if we had not done so. What I think was important and was perhaps then novel, and was certainly essential, was that these men became from the start an integral and vital part of the Air Staff. They were at the heart, and of the heart, of operational planning and that relationship, intimate, close, was, and I believe always will be, the key to success.

The elements for meeting the new urgent need existed only because a programme of radio research had been followed in this country, and in America, which was not directed towards the immediate provision of bigger and better radio sets but which was probing into the fundamental mechanism of the things that happen to radio waves in their travel about the world and of the interfering waves which prevented the fullest and most convenient use of the waves carrying desired communications. The most important lesson for the future which is to be derived from the history and achievement of radar is not contained in the broadly true and gratifying statements that "It may be claimed that radar saved the civilised world", that "Radar has brought about the greatest revolution in naval tactics since the change from sail to steam", that "Radar has, more than any single development since the airplane, changed the face of warfare."

Importance of Fundamental Research

The really important lesson is that it is far more essential in the national interest in peace and in war that there should be an adequate supply of flexible minds and flexible techniques available in the country than that any great concentration of these minds should be put on to the solution of immediate problems and the provision of immediate equipments. It is more important that there should be a large number of scientists free to nose around in other people's business, asking their own questions in their own way, than that there should be large establishments engaged on the production of pieces of equipment designed, however ingeniously and economically, to meet operational requirements that have already been formulated.

The need was known before 1935; the elements of the solution were also known before 1935. The right mixture of minds was made in the early days of 1935, but there was

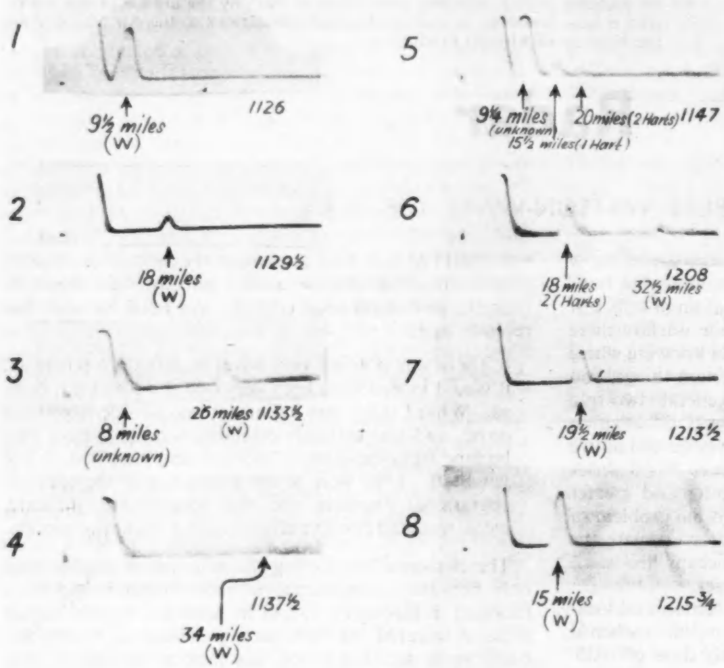


FIG. 1.—The first photographic record of radiolocation of aircraft; made on the 24th July, 1935. A Wallace aircraft was used as the target. There are 8 separate photographs of the cathode-ray tube trace at moments throughout the period of observation, starting with picture No. 1 taken at 1126 hours and ending with picture No. 8 at 1215¾ hours—approximately ¾ hour later.

The time at which each photographic exposure was made is given on the right under each picture. The pictures are numbered consecutively at their left hand extremity.

The "echo" caused by the Wallace aircraft on its outward journey is clearly visible (at increasing distances) in pictures 1 to 4 and on its return journey (at decreasing distances) in pictures 6 to 8. The distance (measured by radar) of the Wallace away from the observing station is shown in miles against the corresponding "echo" in the pictures.

Pictures Nos. 5 and 6 are especially interesting as they indicate a formation of three Hawker Harts which came into radar view uninvited and appeared on the cathode ray tube screen to the surprise of the observers who identified the initial "echo" (not photographed) as a flight of three aircraft, one of which subsequently broke formation and flew off on its own. This was the first radar observation of a flight of several aircraft and the correct interpretation of the "echo" and splitting up of the formation was later confirmed by the pilot of the Wallace, who had himself seen the evolutions from his own aircraft.

one other decisive factor. Those peculiar geographical considerations which contributed to the greatness of London in peace, made it a peculiarly vulnerable target in war. The magnitude of the British contribution to universal disarmament had enhanced that vulnerability. Quite a number of people had thought of the possibility of a radio system for the detection of aircraft; they had all, so far as can be judged, rejected it on the grounds of impracticability. It required the peculiar circumstances of 1935 to produce a detailed scientific and technical argument showing that a practicable system could in fact be produced quickly, but that it was a system which would have been rejected on grounds of low engineering efficiency in almost any circumstances. The triumph of the wise men of 1935 was that they proceeded with proposals which were to utilise, in a moment-to-moment military operation, information which would be conveyed by a radio echo that contained not much more than a millionth of a millionth of a millionth of the energy sent out in the hope of getting a usable echo back. Desperate diseases demand optimistic remedies; as it turned out the optimism was thoroughly justified and the remedies proved to be of vastly more general application than were foreseen at the moment of decision.

The first ground radar station for the location of aircraft was set up on that part of the English coast which is nearest to Germany. Work began on May 13, 1935, and a notable landmark in its progress is shown in Fig. 1. This copy of the photographic record of a test run in which a Wallace aircraft was watched out to 34 miles and picked up on its return trip at 32½ miles shows an interesting intrusion into the experiment. Echoes were received from unknown sources between 15 and 20 miles away. These were diagnosed by the scientific observers as coming from a formation of three aircraft, of which one was judged, on the radar evidence alone, as having broken formation and proceeded independently, the other two remaining in close formation. This diagnosis, the first on a formation of aircraft, was fully confirmed by the pilot of the Wallace on his return. He reported seeing three Harts in a formation from which one detached itself while the other two flew on together.

The method by which this radar information was obtained can be very simply described in relation to the now almost too familiar analogy with a sound echo. A sharp hand-clap is sent back as an echo by such a reflecting surface as a cliff, and the distance of the cliff from the person making the hand-clap can be estimated by counting seconds until the echo is heard. It takes ten seconds for the soundwave to travel to a cliff a mile away and back again, and sound-seconds can be converted into miles at this rate of exchange. If the hand-clapping is loud the echo from the cliff is proportionately loud, if the clapping is continuous the weak echo may not be heard through the

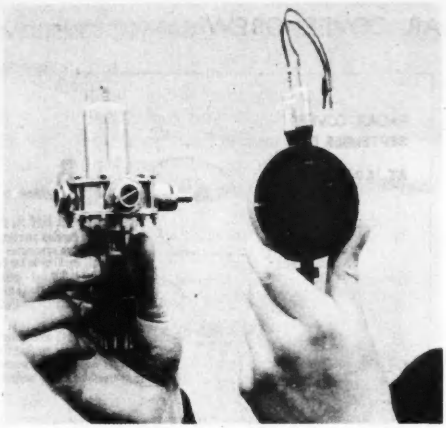


FIG. 2—The magnetron valve (right), alongside another radar component, the "Sutton" tube.

loud and sustained local noise, and if there are several cliffs, each sending back an echo, the echo from any one may be difficult to pick out from the complex of sounds. So the measurement on a particular cliff is best done by making a very loud and very brief bang, and then allowing a silent interval in which the returning echo stands out clearly. The shorter the bang, too, the less overlapping of echoes from slightly different distances occurs.

The radio equivalent of a hand-clap or bang in sound is called a pulse, and almost all practical radar is done by sending out very powerful and very brief pulses, "very powerful" meaning many hundreds of kilowatts and "very brief" meaning a few millionths or a few ten-millionths of a second. The timing of the radio echo has now to be done in millionths of a second, and the rate of exchange is no longer ten seconds (for the double journey out and back) for each mile the echo-producing surface is distant, but ten millionths of a second per mile away. The measuring of millionths of a second is fortunately easy. The cathode ray tube, familiar to the television viewer, depends for its usefulness on the facts that a fine pencil of electrons produce a bright spot on the tube face, and that deflection of the electron beam by electric or magnetic forces can make the spot move, for example, uniformly from left to right in any desired (and reasonable) number of microseconds, stay "off right" for any other desired number of microseconds, jump back very quickly indeed to its starting-point, and repeat the process at any regular rate desired. Another set of electric or magnetic forces can be made to move the spot vertically, and if they come from a radio receiver into which pulses are fed from a receiving aerial, each pulse will make a V-shaped notch on the horizontal line which, by persistence of fluorescence and persistence of vision, is drawn by the fast-moving spot.

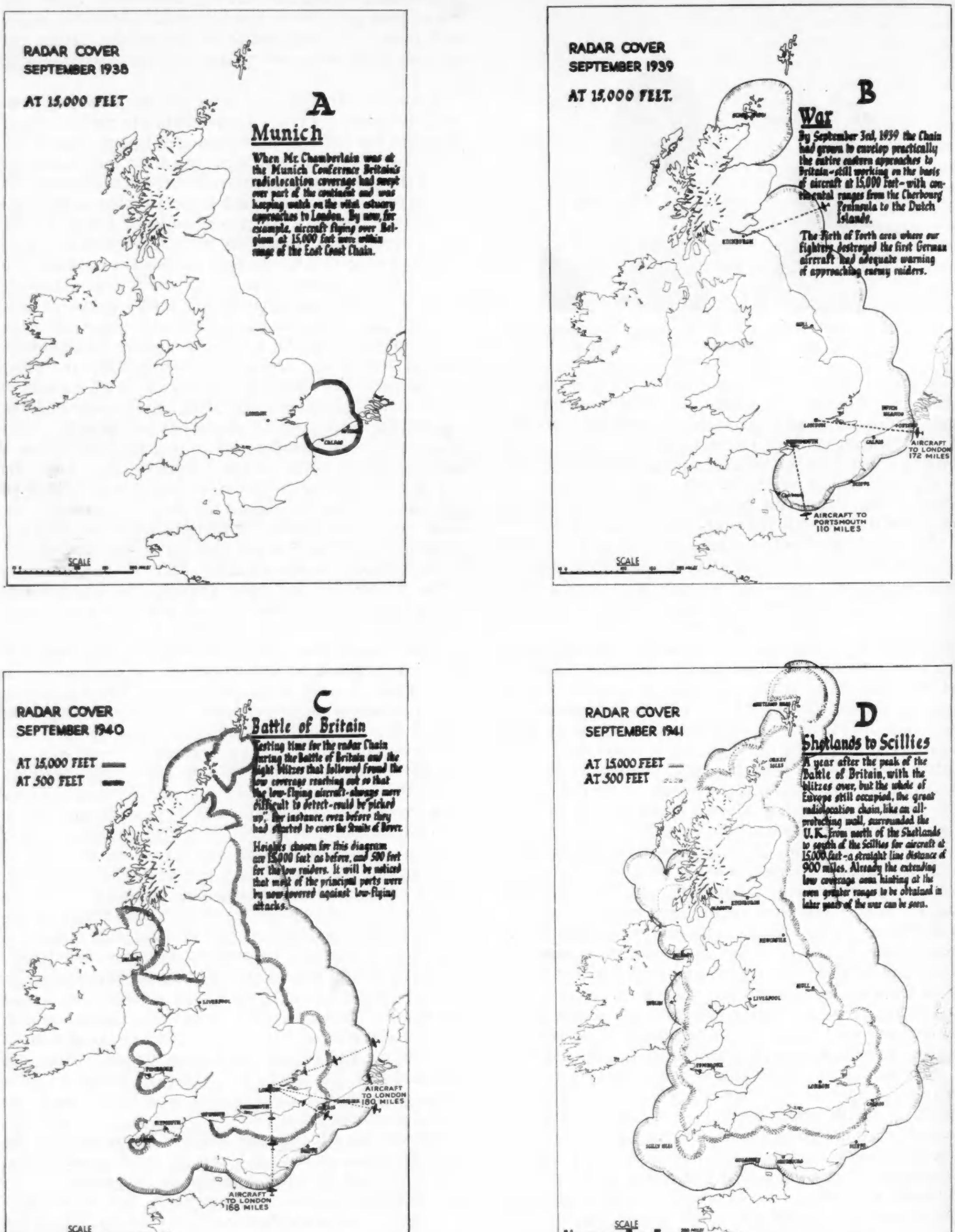
Now we can set up our ground radar system for "early warning of approaching aircraft". We send out powerful pulses at exactly equal intervals (every twenty-fifth of a second if we are going to measure long distances, every five-thousandth of a second for short distances) so that the transmitter is working at a power rating of hundreds of kilowatts or more for about a millionth of a second (a microsecond), is absolutely inactive for the relatively very long time of 40,000 microseconds, then active for a microsecond and so on. We have a big transmitting aerial —a couple of masts 350 feet high are handy supports for it—so arranged that it lets the pulse spread out nearly uniformly over a wide sector in front of the station, but lets very little spread behind, this to avoid confusion with inland aircraft.

A hundred yards or so away we put up a receiving aerial —a 250-foot timber tower is a good thing to put it on—and let it feed the radio receiver connected to our cathode ray tube. Every time a pulse starts out from the transmitter we let the spot on the tube start its left-to-right travel, and the big bang in the receiver due to the wave from a hundred yards away makes a big notch—called a "blip" by the R.A.F. operator, a "break" by the A.A. gunnery operator, a "pip" by the U.S.A. operator—at this left-hand starting end of the horizontal line. Since the line is redrawing itself in exactly the same rhythm as the pulses go out, the blips due to successive pulses are superposed and make a stationary notch. An echo-pulse coming back from an aircraft will arrive later by 10 microseconds for every mile the aircraft is away from the radar station and will make a blip beginning at the point on the horizontal line reached by the bright spot after it has been travelling that number of microseconds. So an aircraft echo makes a slowly moving notch whose left-hand edge reads the distance of the aircraft on the horizontal scale, which we graduate in miles by putting a one-mile graduation for every ten-microseconds left to right travel of the spot. Thus in Fig. 1 (v) the spot had travelled for 92 microseconds (from its simultaneous start with the outgoing pulse) before the first echo arrived, 155 microseconds before the first Hart echo came in, and 200 microseconds before that from the two Harts came in This was all repeated twenty-five times a second, and each blip was nearly superposed on its predecessor for the same echo, so that each aircraft was represented by a blip travelling slowly along the range scale at a rate corresponding to its rate of approach to the station.

This explanation has taken many more microseconds than the whole process described, but the rest is easy. We have found the "slant range" to the aircraft. We need to know its bearing from true North, and its flying height, before we have located it in space. To get the bearing we use a special receiving aerial with one set of horizontal wires pointing due North and South, one set due East and West, and a radiogoniometer in which, by turning a handle, we turn a coil which finds out the proportions of signal in the NS and EW wires. When the coil is pointing directly to the compass bearing of the aircraft, the blip is at its biggest; when it is at right angles to that bearing the blip disappears, and this disappearance gives a very accurate measure of the bearing. Note, then, that we can get a bearing on each blip without confusing it with any other or losing sight of any other. The range and bearing for each echo are unmistakably associated; we cannot by mistake take a range on aircraft A and a bearing on aircraft B and thus plot a ghost aircraft at C!

We still have to measure height. The echo from the aircraft reaches an elevated receiving aerial by two routes, one direct and one after reflection at the ground—which acts as a nearly perfect "radio mirror". But in the reflection process a phase-change of very nearly 180° takes place, which means that each peak in the incident wave is almost exactly replaced by a trough in the reflected wave.

Fig. 3. HOW BRITAIN'S RADAR COVER GREW



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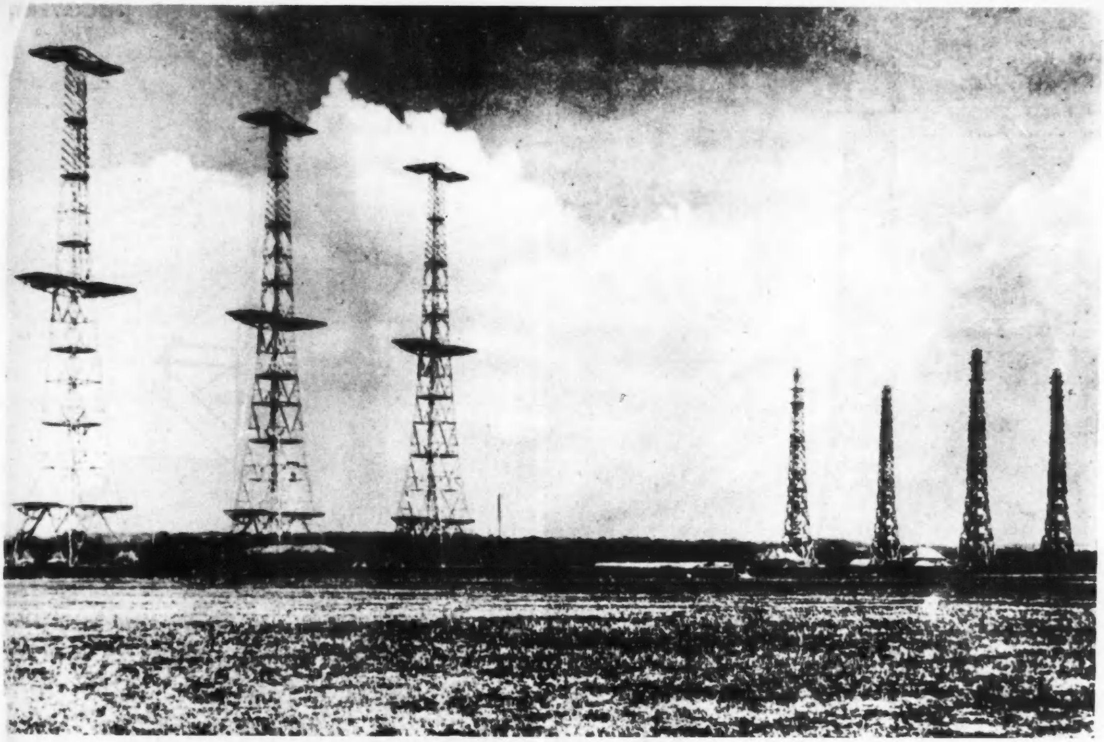


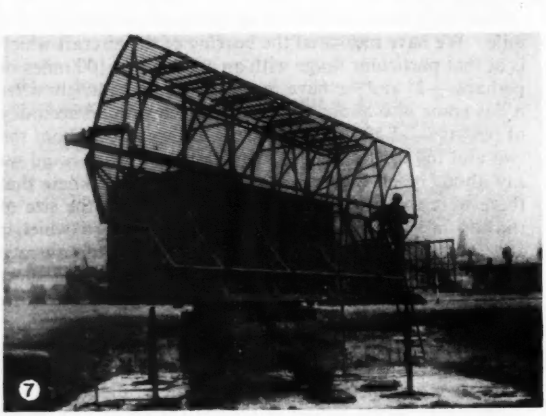
Fig. 4.—A CH (Chain Home) Station

The direct and reflected waves combine to a resultant wave in which they cancel one another out for grazing incidence and reinforce only at higher angles. So a low-flying aircraft gives an extremely weak signal in a low receiving aerial, a better signal in a higher aerial, and in fact a signal which, for low angles of elevation, is proportional to the square of the product of the aerial height and the flying height. So we can measure the flying height by having two receiving aerials at different heights, and comparing the signals in them by switching on to these two aerials the radiogoniometer which we have just used for measuring bearing.

Now let us sit back and reflect how clever we have all been. We have "floodlit" by radar a vast volume of air in front of our station. An aircraft at 10,000 feet 100 miles away will send us back perhaps a thousandth of a millionth of a millionth of the energy contained in each pulse we send out. People who don't know all about the game will say that we did the floodlighting because (in 1935) we hadn't the means of making a powerful radio searchlight. But while it is true that we hadn't, we insisted on floodlighting anyway, and kept it after the radio searchlight came. This was because the first and vital need was for a general watch all the time over all our coastline.

We did not want to lose sight of other formations while we were locating one particular formation. Having set up a chain of stations to give us this general cover, which is shown in Fig. 3 A, B, C and D, we took a second step which is also represented in Fig. 3 C and D. But to go on with our stock-taking. From our one-trillionth-scale echo we have discovered the distance to a single aircraft at one or two hundred miles with an accuracy of round about one mile. We have measured the bearing of the aircraft which is at that particular range with an accuracy at 100 miles of perhaps $\pm 2^\circ$ and we have measured its flying height after it has come into about 60 miles distance with an accuracy of perhaps $\pm 1{,}500$ feet. But how did we know about the two and the three Harts in formation, and what could we say about much bigger formations? Well, we knew that there were two aircraft close together because the size of the blip varied comparatively slowly between zero (which is very nearly reached in Fig. 1 (v)) and twice the average (roughly attained in Fig. 1 (vi)). We knew when there were three aircraft close together because this beating between the two echoes as they passed in and out of phase with one another was rather more rapid and did not cause the blip to fall to zero. As the art of radar progressed our observers, and in particular the W.A.A.F. observers who carried the greatest burden of the coastal watch throughout the Battle of Britain, were able to estimate the number of aircraft in formation up to 100 or 150 with an accuracy of some $\pm 10\%$ in numbers. This was attained by close study and wide experience of the complicated echo pattern given by large formations.

All this information for all the formations in sight has to be passed clearly and accurately to a filter centre which is receiving corresponding information from all the stations along a considerable length of coast. But the information is more conveniently given in the form of a map reference rather than a distance and bearing from any one of the observing stations. Moreover, the measurement of flying height requires correction because of the departure from



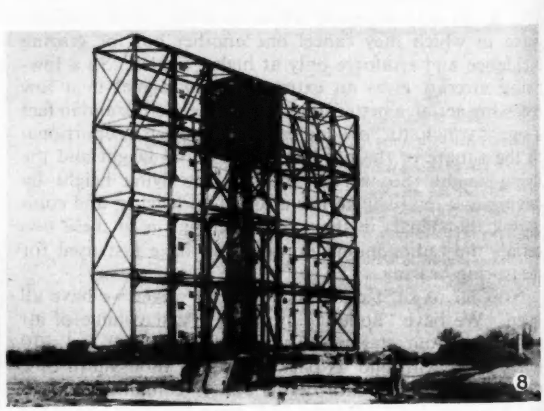


FIG. 5—A CHL (Chain Home, Low) station for detecting and reporting low-flying aircraft. FIG. 6—Height-finding component of modern centimetric mobile ground radar set. FIG. 7—Plan position finding component of modern centrimetric mobile ground set. FIG. 8—A GCI aerial.

absolute uniformity of slope of the ground in front of the radar station. Calibration flights establish what these corrections must be, and the very ingenious electrical calculator which is affectionately, if irreverently, called the "fruit machine" by the radar operators automatically makes these conversions and corrections and displays illuminated figures which are read over the telling line to the filter room.

Now what about the second step? Earlier it was indicated why low-flying aircraft can creep close inshore before being located. The echo strength, which we have described as being proportional to the square of the product of the aerial height and of the flying height, is also inversely proportional to the square of the wavelength, neglecting other wavelength effects which are of secondary importance. To get long ranges on low-flying aircraft, we have to reduce our wavelengths; this reduction of wavelength allows us to use smaller aerials and we can now rotate these aerials about a vertical axis, so getting a limited kind of radio searchlight. This is the CHL equipment (Fig. 5)

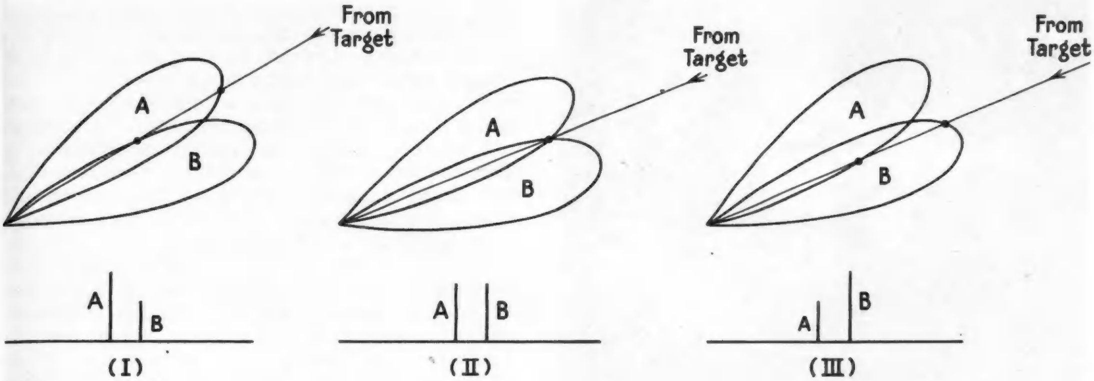


FIG. 9.

which was introduced along the coast in the earliest months of the war to supplement the higher-angle cover given by the big CH stations (Fig. 4); the coverage at 500 feet shown in Fig. 3 C and D is that added by the CHL component of the overall system.

We have to look next at the problems which arose from the fact that even in those early days we had a modest proportion of aircraft of our own to look at along with the enemy aircraft. We wanted, then, some means of discriminating between friend and foe. This was done by fitting to each of the friendly aircraft a comparatively small IFF set which, on receiving the radar pulses, sent back without any appreciable delay a magnified and coded version of them, thus saying "I am a friend", and through changes in the coding, "I am a particular kind of friend".

The Plan Position Indicator

This roughly was the group of equipments—CH, CHL and IFF—which made their contribution to victory in the day Battle of Britain. They were not, however, sufficient to assure success in the night battle. The accuracies of location attained were good enough to bring the intercepting fighter within visual range by day but not within the very much smaller range of vision at night. There had been under development, since quite early in the history of British radar, the AI system in which the complete radar system, transmitter and receiver, was brought down to such a size that it could be carried in the individual night fighter. This, however, was limited in its effective pick-up range to something between $2\frac{1}{2}$ and 4 miles, and an intermediary was needed to bring the night fighter well within these ranges of his quarry before he took over the responsibility of guiding himself into visual contact by the use of his AI set. The intermediary equipment called GCI (Ground Control of Interception) is attained by adding to the CHL set one of the most revolutionary and versatile devices of all radar, namely, the Plan Position Indicator (PPI).

Instead of starting our range scale at the left-hand side of the tube face we can start it at the centre of the face, and we can make it rotate about that centre in exact unison with the rotation of the CHL aerial system which is now projecting a beam roughly some 12° or 15° wide. If, further, we abandon the arrangement of letting the blip appear as a notch on the range scale but instead, by a quite well known method used in television, use the incoming signal to brighten the spot, then it will be seen that we have a system in which the echo is now represented by a bright spot whose position represents in polar co-ordinates the position of the target aircraft on the map—hence the name Plan Position Indicator. The name is not wholly accurate since the measured range is a slant range and not its horizontal projection, but the difference, save at very close ranges, is negligibly small.

It will be clear that since the radio beam is still somewhat wide it would be wrong to think of the bright area corresponding to any particular echo as being really a spot; it is, in fact, a sector of light quite narrow in the radial direction but covering the greater part of the beam width. The bearing of the echo-producing target can, however, be estimated with considerable accuracy by taking the central point of this sector, while its distance is given very accurately by the inner edge of the bright sector. It was with this combination of the CH/CHL on the coast, the GCI set inland and the AI installation in the night fighter itself that the night Battle of Britain was successfully fought in the early months of 1941 and brought to its highly successful conclusion in May of that year. The PPI will appear later in this survey, alike in ground station, shipborne and airborne applications.

There was developed in parallel with the AI set a somewhat similar equipment to be used principally by the aircraft of Coastal Command and of the Naval Air Arm in searching for surface vessels, and in particular for U-boats on the surface, at night or in the presence of mist or low cloud. Even when surface visibility was good there was obviously great advantage to be derived from the ability to shadow a surface ship from an aircraft which could screen itself in cloud cover. The measurement of the slant distance to the surface target was done by the process already described in relation to ground stations, while the relative bearing of the target was measured by the overlapping beam technique which finds application in the CHL and GCI sets already mentioned, in the ground sets for the laying of anti-aircraft and other guns, in "Elsie", the SLC set which allows the searchlight to open directly on its target, and in many forms of shipborne radar. It

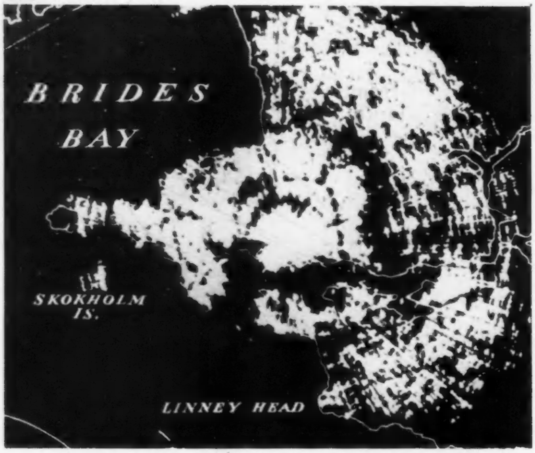


FIG. 10—Radar "map" of the S.W. tip of Wales made by photographing the image thrown on the cathode ray tube of an H2S apparatus in a night-flying aircraft. Nothing has been added to the photograph except the thin outline emphasising the actual coast, and the names. The inlet is that in which Milford Haven and Pembroke are the principal towns.

was indicated in the first paragraphs of this general survey that the optical searchlight suffered from the grave limitation that once the target is out of the beam of light there is insufficient guidance as to the direction in which the beam must be turned to pick up the target. The overlapping radio beam technique completely eliminates this difficulty. It is comparatively easy to swing a radio beam by a few degrees so that at one moment it is pointing a little to the left of its average position and an instant later an equal amount to the right of that position. Fig. 9 shows how the echo from a particular target varies during such a switching cycle and how accurately its bearing can be determined if it is on the crossing point of the two overlapping beams, a condition which is indicated by equality of the two echoes, which can be separately displayed, as shown in Fig 9 (ii). The ASV-equipped aircraft can thus have its heading constantly directed on to the surface vessel to be followed or attacked. Despite complications due to drift in cross winds, visual contact with a U-boat at night can be assured when the radar equipment is supplemented by the particular kind of airborne searchlight called the "Leigh Light".

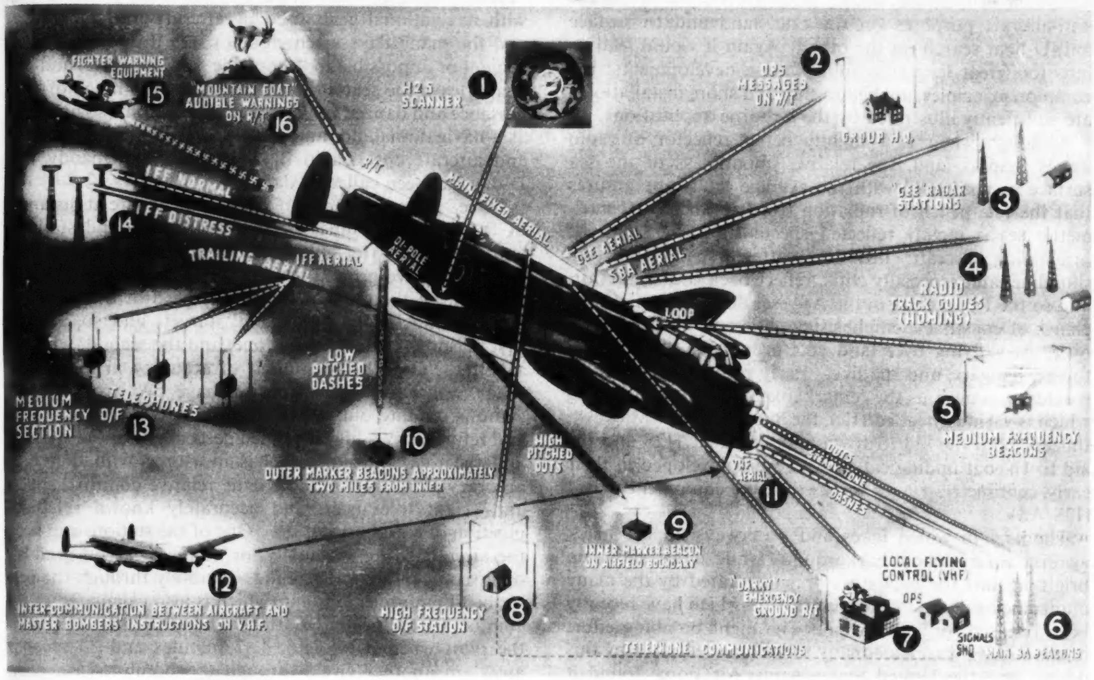
This was the combination of devices which ended the first phase of the Battle of the Atlantic. It was, however, defeated, in accordance with our expectations, by the fitting in the U-boats of radio receiving equipment which allowed the U-boat to submerge before the pursuing aircraft could attack it. Fortunately, plans to meet this enemy counter-action were well advanced before it was applied, and the second phase of the battle will be mentioned when we come to discussion of centimetric radar.

The general principles already outlined need not be traced in their detailed application to the shipborne sets for early warning of impending aircraft attack, to the aids to anti-aircraft gunnery and searchlight laying just mentioned and to the mobile early warning sets which were widely distributed over vulnerable parts of our long lines of communication and battle theatres in the early stages of the war. All of them suffered in greater or less degree from disadvantages and limitations due to the width of the radio beam and the consequent too general illumination, if we may carry over from optics to radio that convenient word which we have already implied in using the terms "radio flood-lighting" and "radio searchlight". The main difficulties due to the width of the beam were of three kinds. The indications on an isolated target were not very accurately readable, because they were in effect painted in with a coarse brush. The indications from closely adjacent targets could not be adequately separated, because the coarse-brush smudges corresponding to each overlapped unnecessarily. And since the ground, whether land or sea, is a good reflector of radio waves, echoes from the ground over a considerable area put additional overlaying smudges on to the already somewhat confused picture. It will be clear from what has already been said that there were ways in which floodlighting and wide-beam illumination were convenient, but there was a long felt and increasingly insistent need for a system in which a really fine pencil of radiation swept systematically, point by point, over the area to be searched, so that only the objects in a very small block sent back echoes at any one instant. Then if we could repeat this systematic point-by-point scanning sufficiently rapidly, the correspondingly fine brush of our electron beam in the cathode ray tube would keep on painting and repainting a sharp and non-smudgy picture showing the plan positions of the reflecting objects.

Centimetric Radar

These needs would be met only by much shorter wavelengths, because there was no way in which fine radio beams could be produced except by aerials and radio mirrors many wavelengths in aperture, and only if the wavelength were brought down to ten centimetres or less could mirrors of sufficient aperture (measured in wavelengths) be carried in aircraft or even in mobile ship and shore equipments. The demand for high pulse-powers and high receiver sensitivities on centimetric wavelengths had to be met.

It could only be met by that zeal which is born of personal conviction that the need is real and pressing, combined with the knowledge and ingenuity of the physicist-researcher. It was met in this case because, under the growing menace of war in prospect, the small pre-1939 band of radar workers was in the spring of 1939 greatly reinforced. Some ninety of our most brilliant younger physicists were invited to study radar at work in the coastal chain, to discover its needs and to prescribe solutions. They were immediately impressed by the urgency of the centimetric-wave need, and in particular the gifted team which Professor M. L. E. Oliphant had gathered about him at Birmingham University undertook the task of providing a valve to generate power far in excess of anything hitherto attained on centimetric wavelengths. Randall produced the modern magnetron by applying to the older magnetron the newer resonant-cavity technique; others—all, like Professor Oliphant, Professor J. T. Randall and their colleagues working under the general aegis of the Admiralty, to whom had been confided responsibility for valve development for all services—produced novel receiving valves to match, and centimetric



RADAR DEVICES IN A LANCASTER. A fully equipped plane had 40-50 radio "boxes," using more than 300 valves. This diagram indicates how many navigational aids radar provides.

(1) H2S scanner, housed in a blister below the R.A.F. roundel. (2) Wireless telegraphy link with Group H.Q. (3) "Gee" system of navigations, based on information from a series of ground stations. (4) As homing bomber approaches coast, radio track guides (using Standard Beam Approach aerial) assist navigator. (5) Medium frequency beacons provide direction-finding facilities, using loop aerial inside plane. (6) Main Beam Approach beacons give steady signal tone if pilot is on correct line of approach to aerodrome; too far to port, he hears series of Morse dots, too far to starboard series of dashes. (7) Airfield signals, operations and flying control are all linked by 'phone with (8) the airfield's high-frequency D/F station. Flying Control has a V.H.F. link with aerial (11); and a "Darky" or emergency radio-telephone link to the ordinary R/T aerial, if all other radio aids fail.

(9) and (10), the inner marker beacon on the aerodrome boundary, and outer marker beacons 2 miles away, give pilot his distance from runway in final stages of a beam approach, using di-pole aerial. (12) V.H.F. communication with other aircraft. (13) Medium frequency D/F stations, which are widely spaced, up to 6-700 miles apart. The aircraft uses trailing aerial, wound off a drum. (14) IFF—Identification Friend or Foe—system with special aerial. IFF distress version is used by aircraft in difficulties to call the ground stations' attention. (15) Fighter warning equipment, warns bomber crew against aerial attack. (16) "Mountain Goat" device gives audible warning of nearby mountains; ground installations need to be erected on the mountains.

radar was ready to revolutionise most of the applications of this highly versatile art of radiolocation.

The first concentrated drive for centimetric waves had come from those concerned with AI sets. The effect of echoes from the ground in the older one and a half metre sets had been to obscure any aircraft echo coming from a distance greater than the flying height of the night fighter, since echoes poured in from ground at all distances in excess of that of the nearest ground—that vertically below. It was therefore natural that the first centimetric radar set to be produced was an AI set with an ingenious mechanical scanning system which greatly reduced the ground-echo troubles and greatly enhanced the accuracy of location of the bomber by the intercepting fighter. This new equipment, since the first model took to the air in February 1941, did not have so many "customers" to deal with as its predecessors, but it did invaluable work at home, in North Africa and the Mediterranean, and in the liberation of Europe.

The experimental AI sets were immediately turned over towards development of the centrimetric ASV which should defeat the expected U-boat listening sets, not yet fitted. Between March 1943 and the end of June the use of something between fifty and a hundred centimetric ASV sets, with their airborne PPI display system, saw the end of the U-boat menace; the combination of ASV-equipped aircraft (in Coastal Command and Naval Air Arm) and radar-equipped surface vessels, destroyers and corvettes in particular, brought what the Führer optimistically called a "temporary setback to our U-boats . . . due to one single technical invention of our enemies." The recovery from the "temporary" setback was not achieved before the final defeat of Germany.

The radar sets for destroyer and corvette developed

from a laboratory model of ground centrimetric radar which showed the way towards centimetric gun-laying for anti-aircraft purposes on the one hand and to surface anti-U-boat search on the other. Again it would lead us into too great length to follow these developments; the common principles, applied to ship and shore installations, are sufficiently illustrated by the airborne applications.

Although water is a slightly better reflector of radio waves than is land, the relative smoothness of the sea surface as compared with the average landscape ensures that the fine pencil of radiation from an airborne centrimetric set is mostly reflected specularly away from the originating aircraft; little is scattered back. But the shoreline, and especially cliffs, reflect back to the aircraft, and so the PPI picture in the ASV set draws rough outline charts of coastlines, emphasising cliffs and inlets. Moreover, ASV flying over land gets prominent echoes from towns, hangars, and the like. Early recognition that this would be so gave us the remarkable aid to night bombing which is variously called H2S, the "gen box" or "Mickey". Indeed, both the aid to town-finding called H2S and the aid to U-boat finding called ASV were developed in their early centimetric stages as a common equipment called H2S/ASV.

The way in which lakes and waterways appear black against a faint land background, while cities show up bright against the background, is illustrated by the many photographs of the PPI display in H2S which have recently been released for publication. The night bombing effort of the R.A.F. was made many times more effective by this device, and the United States Army Air Force found it possible to multiply by a similar factor the number of days on which they could bomb effectively in European weather, with its characteristic long spells when "bombing through overcast" alone could be practised (Fig. 10).

Meanwhile, other aids to the bomber offensive had grown out from the original radar stem. One of them, the "Gee" system, which was the most widely installed of all radar systems, did not depend on radar echoes at all, but it used pulses and all the associated techniques which are the essential features of radar, and "Gee" is thus indubitably a radar system. Without "Gee" the thousand-bomber raid, and, far more important, the very close concentration of night bombers in space and time over their target, of which the thousand-bomber raid was a crude precursor, could not have been achieved.

If we send out pulses simultaneously from two ground stations, an aircraft fitted with a pulse-receiver cannot measure his distance from one or the other, because he has no way of knowing when the pulse started out on its journey. But he can measure how much later the one arrives than the other, and thus how much farther away B is than A. He can, in fact, discover on which of a whole family of curves of equal time-difference and thus of equal distance-difference (hyperbolas) he is. And if a third station C also sends out synchronised pulses he can find on which of another set of hyperbolas he is, and so where he is on the map. "Gee" and its American brother "Loran" have now covered a great part of the world map with navigational grids used by aircraft and ships alike; and the many days when clouds make it difficult, inconvenient or impossible to "shoot the sun" (or stars) and one has to leave the sextant in its case have lost much of their nuisance and danger value. "Gee" has become so universal as a navigational aid, and was so valuable to all the ships and aircraft engaged in the assault on Normandy that D-day has been called G-day.

"Gee" gives accuracies of a few miles square at distances of three hundred miles or so from the ground stations, and about a quarter-mile square near the mid-point of the line joining two ground stations. But this satisfies neither the pride of the radar man nor the need of the precision bomber attacking a "pin-point" target; and so, for the first reason, which is a good one, and the second, which is a better, "Oboe", the summit of accuracy in long-range radar, was born. Here, too, we have two ground radar stations sending out pulses, but the pulses are picked up and returned by a highly refined descendant of the IFF set, and the total time of travel is measured with that high accuracy that is permitted by the relative comfort, space-and-weight tolerances, and accurately known reference position of a ground station. One of the stations can keep the aircraft flying (manually, or automatically if need be) on a sector of a circle passing accurately through the prescribed bomb-release point (which is also calculated in the comfort of the ground station) while the other can warn the pilot when he is 8, 6, 4, 2 minutes and 30 seconds away on another circle through the bomb-release point (each circle being, of course, a line of constant distance from the station concerned) and can, if need be, release the bombs automatically from the bomb-rack of an aircraft whose position he knows far more accurately than do its occupants. Errors of about 200 yards in combat conditions and a few tens of yards in practice-range conditions can be attained at distances near 200 miles, and it is satisfactory to record that the Ordnance Survey and its German counterpart agreed so well within this accuracy as to facilitate "Oboe" operation. It is not too much to claim that the Battle of the Ruhr was won by this most spectacular of radar devices.

Even in war radar was far from being solely an instrument of destruction, superlatively though it filled that unpleasantly essential role. For its range of aids to navigation, by radar beacons on the IFF principle guiding the returning flyer home to "Mother", by tracking the "lost" training or operational aircraft within the coverage of the coastal and inland stations, thus making possible radio instructions about the course to set towards safety, by watching coastal shipping groping past minefields and marine hazards in fog, by eliminating fog and ice hazards on the high seas—an iceberg ten miles away, a growler three miles away announce themselves on the PPI—in a multiplicity of such ways radar is well set on its own course towards safety of sea and air travel in the peace.

British Council's Agriculture Department

DR. W. T. WILLIAMSON who has had experience in Egypt as chief chemist to the Ministry of Agriculture, has been appointed director of the newly-created Department of Agriculture in the British Council.

Centenary of "Scientific American"

DISCOVERY sends greetings to the editor and staff of *Scientific American* on the occasion of that paper's centenary. *Scientific American* has been in continuous publication ever since 1845. Until 1921 it was a weekly paper, with a monthly supplement dealing with more technical matters than those dealt with in the main journal. The paper's long run probably owes much to a flexible editorial policy, a character peculiarly essential to journals in this field which seek to trace the ever changing line of scientific and technological progress. Control of *Scientific American* has always rested with the same family, the original publisher being Orson D. Munn, grandfather of the present publisher. The present managing editor is Mr. A. P. Peck.

Three New Periodicals

THE origin and history of ASLIB—the Association of Special Libraries and Information Bureaux, whose work ought to be better known than it is at present, appropriately forms the subject of the first article in the quarterly publication just launched by this organisation. Entitled *The Journal of Documentation*, it is intended to deal with the "recording, organisation and dissemination of specialised knowledge". The scientist is likely to be most interested in an article by N. W. Pirie who puts forward tentative proposals, deserving of wide discussion, to meet the scientist's difficulties in keeping pace with "the literature". He suggests that by a financial arrangement a hundred or so British scientific journals could be interlocked so that one subscription to a single journal would entitle the subscriber to receive on request a reprint of any paper from any of the other participating journals. He also outlines a proposal that aims at reducing the amount of reading a scientist has to do; "extended summaries" would be published in the most suitable journal and those who required more detailed information would apply for the full paper (which Mr. Pirie envisages as being rather longer than the present day average), copies of which would be produced, preferably by offset printing, from a master copy. The full paper might be published by the journal carrying the extended summary, or by a central authority. Summaries and full papers would be presented simultaneously. ASLIB's new journal costs 25s. a year to non-members. The association has also just published a book, *Manual of Special Library Technique*, by J. E. Wright, who has had 20 years' experience of this kind of service in the Post Office Engineering Research Department; the price to non-members is 8*s*. 6*d*.

To maintain during this war the standard of an already existing periodical is not the simplest of tasks; to bring out a new one for a readership of problematical size is courageous indeed, and we are prompted to an expression of admiration at the energy and courage of editors and publishers that must lie behind the appearance of *New Biology*. We feel, however, that it is support rather than admiration that the editors, M. L. Johnson and Michael Abercrombie, both of the zoology department of Birmingham University, are hoping for. We commend *New Biology* to our readers' attention, for the first number is very good value. By its level of approach we were reminded of *Science Progress* (the resumption of publication of that journal would be welcomed by many), but *New Biology* restricts its scope, of course, to the biological sciences. We wish it every success and hope that it will be possible for Penguin Books to bring out a second number soon. *New Biology* costs 9*d*.

A useful article on world power resources and social development appears in the first number of *Pilot Papers*, which is edited by Charles Madge and published by the Pilot Press at 3*s*. 6*d*. Articles on scientific subjects in relation to human affairs are likely to appear regularly in this new journal, which we understand may be expected to be printed quarterly.

Cysteine and Famine

CYSTEINE, an essential animo-acid, is being incorporated into pre-digested famine foods. It is being made on a large scale from human hair collected from barbers' shops, but the demands arising from the relief of starvation on the Continent are such that this source is likely soon to prove inadequate and animal hair will probably have to be used. Human hair, containing 11-12 per cent cysteine, is a richer source of the amino-acid than either sheep's wool (7 per cent cysteine) or horse hair (8 per cent).

Research on Animal Breeding

THE Agricultural Research Council has appointed to its scientific staff Professor R. G. White, Professor of Agriculture in the University College of North Wales, Bangor, and Dr. C. H. Waddington, of the Department of Zoology, Cambridge University, whose first task will be to prepare a scheme for the creation of a national organisation for research in animal breeding and genetics covering the needs of Great Britain. They will begin by investigating the systems adopted in other countries for the development of research in this field, so that a complete scheme cannot be ready for some time, and it cannot be indicated at present what centre or centres will be chosen for the development of research. The Council is however, anxious that in any new developments full advantage should be taken of the experience of the Institute of Animal Genetics at the University of Edinburgh, which for so long has contributed to knowledge of these subjects and has been the centre of post-graduate training for workers from many countries. Similarly, it is the Council's intention that by close co-operation with practical breeders and the representatives of the agricultural industry throughout Great Britain, as well as with Milk Marketing Boards and other interested organisations, arrangements shall be made whereby records are kept in such a form as to give the greatest measure of assistance to research workers in the new organisation and to be of real value in guiding the improvement of livestock.

Research on such slow-breeding animals as farm stock must necessarily be lengthy, and results which can be applied with confidence in breeding practice cannot be expected to emerge quickly.

Aeronautics College Opening Next Year

PROFESSORSHIPS for the new College of Aeronautics have now been advertised. Applications for these posts, which carry a salary of £1,700 a year, had to be received by September 15. The board of governors of the college, which is being set up in accordance with the recommendations of the committee presided over by Sir Roy Fedden (this report received comment in our columns in December last year), has been appointed.

The following are on the board: Air Chief Marshal Sir Edgar Ludlow-Hewitt (chairman), Dr. W. Abbott, Mr. H. Burroughes, Sir Roy Fedden. Mr. J. Ferguson, Sir Harold Hartley, F.R.S., Sir William Hildred, Sir Melvill Jones, F.R.S., Dr. E. B. Moullin, Mr. J. D. North, Sir Frederick Handley Page, Mr. E. F. Relf, F.R.S., Dr. H. Roxbee-Cox, Lord Selkirk, Air Marshal Sir Ralph Sorley, Sir William Stanier, F.R.S., Rear-Admiral T. H. Troubridge, and Mr. W. E. F. Ward. Preliminary steps are now being taken with a view to opening the college some time next year in temporary accommodation at Cranfield, pending the provision later of permanent premises.

Forces' Natural History Clubs

ORGANISED natural history among the Forces in the Middle East has achieved a very high standard in scientific field work, writes Eric Hardy. Not only do naturalists' clubs exist at Jerusalem, Baghdad, Damascus, Haifa, Cairo and other centres, issuing regular printed or duplicated bulletins of their observations and discoveries, but under the Middle East Biological Scheme several expeditions have been formed to collect specimens for the British Museum. These have covered Lake Tiberias, Lake Huleh, the Mount Cassius district of Turkey, the Lebanon area of Syria, the Dead Sea, etc., while a guide book to the birds of the Nile Delta was printed, with coloured illustrations, in Cairo, where special bulletins of bird migration observations in the Nile Delta area have received official publication. In India much field work and original study has been organised through the famous Bombay Natural History Society although the Forces have organised their own local area naturalists' societies, for example near Cawnpore. The American troops in North Africa organised the collecting of specimens for American museums.

It will be remembered that it was the presence of British troops in the Near East in the Great War which added so much to the knowledge of fauna and flora

of little worked areas, notably Col. Meinterzhagen's ornithological studies which resulted in his edition of Nicholl's Birds of Egypt, and Philip Gosse's collections of mammals for the British Museum made while he was serving with the 5th Army in France.

The naturalists' club formed amongst members of Paiforce at Baghdad early in 1945 has made some interesting studies of the habits and flights and travels of bats. Many observations show the value of the rose-coloured starling eating locusts in the hopper stage. A white stork found shot near Nasiriya in March bore a Rossitten (German) migration ring on its leg.

The Haifa Club's expedition to Lake Huleh in northern Palestine in April collected an unusual black gecko in the ruins at Capernaum beside Galilee, and at the lake caught the unique blind prawn known to occur elsewhere only in a locality near Tiberias. Altogether the party collected some 500 insects and some 100 species of plants, together with a list of some 50 species of birds observed. Altogether the Damascus Club has collected some 1600 plants, 270 birds, 637 shells and over 2000 insects for the British Museum.

Academy of Sciences: New Building

CONSTRUCTION of the main building of the Academy of Sciences of the U.S.S.R. on the bank of the Moskva River—interrupted by the war—has been resumed. The seven-floored building will occupy an area of 2,100,000 square feet. It will contain a library capable of holding 6,000,000 volumes, two museums and a conference hall to seat 1,000 persons.

Night Sky in October

The Moon.—New Moon occurs on October 6d. 05h. 22m., U.T., and full moon on October 21d. 05h. 32m. The following conjunctions take place:

October		
3d. 12h.	Venus in conjunction with the moon	Venus 4° S.
27d. 05h.	Mars ,,	Mars 0·8 S.
27d. 05h.	Saturn ,,	Saturn 2 S.

In addition to these conjunctions, the following conjunctions take place: Mars is in conjunction with Saturn on October 26d. 07h., Mars being 1·4°N.; Venus is in conjunction with Jupiter on October 30d. 08h., Venus being 0·5°N.

The Planets.—Mercury is in superior conjunction with the sun on October 2 and is unfavourably placed for observation throughout the month. Venus can be seen in the morning hours, rising at 3h. 12 m., 3h. 56m., and 4h. 00m., at the beginning, middle, and end of the month respectively. Mars rises at 22h. 08m. at the beginning and at 21h. 15m. at the end of the month. Jupiter is in conjunction with the sun on October 1. At the middle of the month the planet rises an hour before the sun and at the end of the month about 2h. 10m. before the sun, and can be seen in the morning hours. Saturn rises at 23h. 07m. and 21h. 15m. at the beginning and end of the month respectively.

Times of rising and setting of the sun and moon are given below, the latitude of Greenwich being assumed:

October	Sunrise	Sunset
1	6h. 00m.	17h. 39m.
15	6h. 23m.	17h. 08m.
31	6h. 51m.	16h. 36m.

October	Moonrise	Moonset
1	0h. 14m.	16h. 23m.
15	15h. 03m.	23h. 28m.
31	1h. 36m.	15h. 37m.

The Orionid meteor shower is due about the third week in October but moonlight will partly interfere with the observation of the meteors.

Many interesting objects can be seen in the autumn constellations with field-glasses or a small telescope. The Great Nebula in Andromeda, which is just visible to the naked eye close to the star Nu, is easily seen with a small instrument. It is one of the closest of the extra-galactic nebulae and is a little smaller than our Galaxy. An interesting double star β Cygni can be easily seen with a small telescope. The larger star, of third magnitude, is a topaz yellow, and the smaller one a sapphire blue, and the contrast is a beautiful sight. The star 61 Cygni is not a spectacular object, being only magnitude 5, but it is famous by the fact that it was one of the first stars whose distance was determined by Bessel, a German astronomer. It is comparatively close to us—about 10 light years distant. The great rift in the Milky Way in the constellation of Cygnus can be easily seen and is due to obscuring clouds which intercept the light of the stars beyond.

M. DAVIDSON, D.SC., F.R.A.S.

JUNIOR SCIENCE

To-morrow's Weather—II

LAST month I told you how many different things concerning the state of the air in and around our local region the meteorlogist has to know before he can predict the kind of weather we are going to have in the next twenty-four hours. You will probably understand now why it is much more difficult to forecast to-morrow's weather than the eclipses of sun and moon that will occur many years from now. Of course the real trouble about weather forecasts is that they have to be rather detailed if they are to be of use to the farmer, the airman and the holiday-maker. If we were content with more general statements, weather predicting would be much easier. For instance, I can tell you with considerable certainty that the 4th of February, 2347 will be a much cooler day in London than the 2nd of August of the same year, and that it will be the other way round in Cape Town. The reason for the accuracy of this remarkable forecast is of course that the position of the earth's axis in respect to its orbit around the sun influences the weather conditions much more than all other factors so that in London February, when the northern hemisphere is averted from the sun, is bound to be colder than August, when it faces the sun.

There are other general factors which have a fundamental influence on the weather. Near the equator, where the ground receives the maximum of solar radiation, the air near the surface of the earth is warmed and rises. Cooler air from the north and south takes its place and thus we get steady winds which are directed towards the equator while in the neighbourhood of the equator itself we get a region of comparative calm where the air is rising—the "doldrums". Because the earth is rotating, the winds blowing towards the equator are not due north and south; a point at the equator moves faster than a point on the northern or the southern hemisphere, and as air moving over the earth's surface lags behind this movement of the ground we get north-easterly winds and south-easterly winds. These steady winds were of very great importance when all ocean navigation relied on sailing ships, and they were named the "Trade Winds". The seasonal changes, together with the influence of the earth's rotation and the temperature of the ocean currents, produce regular weather changes in certain parts of the globe which can be relied upon and predicted with fair accuracy; this is possible, for instance, for the rain-bearing monsoons in the territories around the Indian ocean.

Unfortunately for our meteorologists the Trade Winds do not extend to the latitude of the British Isles and there are no fundamental influences, except the seasonal changes, on the regularity of which we can rely for our forecasts. Instead, our weather men have to depend on the reports from many hundreds of meteorological stations at which air temperature, humidity, rainfall, wind speed and direction, and many other details are noted. From all these reports weather maps covering Europe and great parts of the Atlantic and Arctic oceans are compiled. With painstaking labour and much experience it can be deduced from these maps that you can go sun-bathing tomorrow afternoon in Brighton whereas those in North Wales would be advised to take an umbrella along. K.M.

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